BULLETIN

OF THE

GEOLOGICAL SOCIETY

OF

AMERICA

VOL. 30

JOSEPH STANLEY-BROWN, Editor

NEW YORK
PUBLISHED BY THE SOCIETY
1919

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PUBLICATIONS OF THE GEOLOGICAL SOCIETY OF AMERICA

Regular Publications

The Society issues annually, in four quarterly parts, a single serial octavo publication entitled Bulletin of the Geological Society of America, the edition being 700 copies. A small supply of authors' separates of the longer articles is kept for sale by the Secretary at the prices quoted in each volume.

The Bulletin is sold at the uniform price of ten dollars ($10.00) per volume, with a discount of twenty-five (25) per cent to Fellows of the Society, persons residing elsewhere than in North America, and public and institutional libraries; carriage extra. Subscriptions are payable in advance. Regular subscribers within the United States of America and its possessions receive their parts, postage paid, as issued. Forty (40) cents per volume must be added to the subscription price to cover postage to other countries in the Postal Union.

The price of the index to volumes 1-10 is $2.25 and of the index to volumes 11-20 is $3.50; carriage extra. No reduction is made to dealers. Orders should be addressed to the Secretary, whose address is care of the American Museum of Natural History, New York, N. Y., and drafts and money orders should be made payable to *The Geological Society of America.*

Description of the Published Volumes

Volumes.	Pages.	Plates.	Figures.
Vol. 1, 1889	593 + xii	13	51
Vol. 2, 1890	622 + xiv	23	63
Vol. 3, 1891	541 + xi	17	72
Vol. 4, 1892	458 + xi	10	55
Vol. 5, 1893	655 + xii	21	43
Vol. 6, 1894	528 + x	27	40
Vol. 7, 1895	558 + x	24	61
Vol. 8, 1896	446 + x	51	29
Vol. 9, 1897	460 + x	29	49
Vol. 10, 1898	534 + xii	54	83
Index to volumes 1–10	209	..	..
Vol. 11, 1899	651 + xii	58	37
Vol. 12, 1900	538 + xii	45	28
Vol. 13, 1901	583 + xii	58	47
Vol. 14, 1902	609 + xii	65	43
Vol. 15, 1903	636 + x	59	16
Vol. 16, 1904	636 + xii	94	74
Vol. 17, 1905	785 + xiv	84	96
Vol. 18, 1906	717 + xii	74	59
Vol. 19, 1907	617 + x	41	31
Vol. 20, 1908	749 + xiv	111	35
Index to volumes 11–20	422	..	..
Vol. 21, 1909	823 + xvi	54	109
Vol. 22, 1910	747 + xii	31	66
Vol. 23, 1911	758 + xvi	43	44
Vol. 24, 1912	737 + xviii	36	60
Vol. 25, 1913	802 + xviii	28	47
Vol. 26, 1914	504 + xxi	27	41
Vol. 27, 1915	739 + xviii	30	55
Vol. 28, 1916	1005 + xxii	48	102
Vol. 29, 1917	679 + xix	22	67
Vol. 30, 1918	644 + xiii	15	40

Parts of Volume 30

	Pages.	Plates.	Figures.	Price to Fellows.	Price to Public.
Number 1	1–188	1– 6	----	$2.05	$3.05
Number 2	189–338	[1]7–10	20	2.25	3.35
Number 3	339–422	11–13	13	.95	1.40
Number 4*	423–644	14–15	7	2.35	3.50

[1] Colored map.

Reprints from Volume 30

Reprints.	Pages.	Plates.	Figures.	Price to Fellows.	Price to Public.
Proceedings of the Thirty-first Annual Meeting of the Geological Society of America, held at Baltimore, Maryland, December 27 and 28, 1918. Edmund Otis Hovey, *Secretary*	11– 42	1– 6	----	$1.65	$2.55
Proceedings of the Tenth Annual Meeting of the Paleontological Society, held at Baltimore, Maryland, December 28, 1918. R. S. Bassler, *Secretary* †	143–164	----	----	.20	.30
Geology in the world war and after. Whitman Cross	165–188	----	----	.25	.35
Outlines of the geology of Brazil to accompany the geologic map of Brazil. J. C. Branner	189–338	7–10	1–20	2.25	3.35
Geology and stratigraphy of the area of Paleozoic rocks in the vicinity of Hudson and James bays. T. E. Savage and F. M. Van Tuyl	339–378	11–13	1– 4	.50	.75
Camarasaurus, amphicœlias, and other sauropods of Cope. H. F. Osborn and C. C. Mook †	379–388	----	----	.10	.15
Chalk, flints, and ground-water of northern France. E. M. Burwash	389–398	----	1– 2	.10	.15
Military contribution of civil engineers. G. O. Smith	399–404	----	----	.10	.15
Military and geologic mapping—a plane-table. A. M. Bateman	405–414	----	1– 5	.10	.15
Topographic features of the Hudson Valley and the question of post-Glacial marine waters in the Hudson-Champlain Valley. J. H. Stoller	415–422	----	1– 2	.10	.15
Significance of the Sherburne sandstone in Upper Devonic stratigraphy. A. W. Grabau†	423–470	----	1– 2	.50	.75
Permo-Triassic of northwestern Arizona. H. W. Shimer†	471–498	----	1	.30	.45
Evolution of geologic climates. F. H. Knowlton †	499–566	----	----	.70	1.05
Coal Measures of Maryland. C. K. Swartz, W. A. Price, and Harvey Bassler†	567–596	14–15	1	.35	.45
Post-Glacial uplift of southern New England. H. L. Fairchild	597–636	----	1– 3	.40	.60

* Preliminary pages and index are distributed with number 4.

† Under the brochure heading is printed Proceedings of the Paleontological Society.

Irregular Publications

In the interest of exact bibliography, the Society takes cognizance of all publications issued wholly or in part under its auspices. Each author of a memoir receives 30 copies without cost, and is permitted to order any additional number at a slight advance on cost of paper and presswork; and these reprints are identical with those of the editions issued and distributed by the Society; but the cover bears only the title of the paper, the author's name, and the statement [Reprinted from the Bulletin of the Geological Society of America, vol. —, pp. —, pl. — (Date)]. Contributors to the Proceedings and "Abstracts of Papers" are also authorized to order any number of separate copies of their papers at a slight advance on cost of paper and presswork; but such separates are bibliographically distinct from the reprints issued by the Society.

Regular Editions

Pages	165–188,			240	copies.	March	31, 1919.
"	189–338,[1]	plates	7–10,	90	"	June	30, 1919.
				350	"	April	15, 1920.
"	339–378,	"	11–13,	240	"	September	30, 1919.
"	379–388,*†			665	"	"	30, 1919.
"	389–398,			140	"	"	30, 1919.
"	399–404,			440	"	"	30, 1919.
"	405–414,			110	"	"	30, 1919.
"	415–422,			40	"	"	30, 1919.
"	423–470,*†			365	"	December	31, 1919.
"	471–498,*†			165	"	"	31, 1919.
"	499–566,*†			215	"	"	31, 1919.
"	567–596,*†	"	14–15,	435	"	"	31, 1919.
"	597–636,			90	"	"	31, 1919.

Special Editions‡

Pages	13– 27,	plate	1,	140	copies.	March	31, 1919.
"	27– 36,	"	2,	40	"	"	31, 1919.
"	37– 42,	"	3,	40	"	"	31, 1919.
"	43– 47,	"	4,	90	"	"	31, 1919.
"	47– 65,	"	5,	90	"	"	31, 1919.
"	66– 76,	"	6,	335	"	"	31, 1919.
"	119–130,			40	"	"	31, 1919.
"	131–142,			240	"	"	31, 1919.
"	143–164,			165	"	"	31, 1919.

[1] Also translated into Portuguese and published by the Brazilian Government, as pages 1-152, June 30, 1919.

* Bearing on the cover

PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY.

[Reprinted from the Bulletin of the Geological Society of America, vol. ——, pp. ——, pls. ——, (Date)].

† Under the brochure heading is printed PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY.

‡ Bearing imprint [From Bull. Geol. Soc. Am., Vol. 30, 1918.]

CORRECTIONS AND INSERTIONS

Contributors to volume 30 have been invited to send corrections and insertions to be made in their papers, and the volume has been scanned with some care by the Editor. The following are such corrections and insertions as are deemed worthy of attention:

Page 122, line 1 at bottom; *for* "Isaac Marcus Goldman" *read* Marcus Isaac Goldman.
" 211, line 16; *for* "Renault, Z. H." *read* Renault, D. H.
" 212, line 32; *for* "Paulo" *read* Paula.
" 216, line 23; *for* "Curvelho" *read* Curvello.
" 244, line 2; *for* "1866" *read* 1886.
" 268, line 27; *for* "Galogeras" *read* Calogeras.
" 269, last line; *for* "Berby" *read* Derby.
" 290, line 18; *for* "ragião" *read* região.
" 299, line 6 from bottom; *for* "Trinidade" *read* Trindade.
" 316, line 8 from bottom; *for* "Itapurû" *read* Itapura.
" 391, last line; insert "some" before detail.
" 394, line 13; *for* "some distances" *read* such distances.
" 396, lines 28-9; *for* "as stated formed" *read* formed as stated.
" 397, line 8; *for* "drift," *read* residual deposit.
" 397, line 31; *for* "deepens" *read* was deepened.
" 406, line 4 from top; *for* "Reserve Officers' Training Camp" *read* Reserve Officers' Training Corps.
" 406, line 5 from top; *for* "Students' Auxiliary Training Camp" *read* Students' Army Training Corps.
Pages 416, 418, and 420, running heading; *for* "J. M. Stoller" *read* J. H. Stoller.
Page 421, line 6 from top; *for* "Baldwin" *read* S. P. Baldwin.

BULLETIN

OF THE

Geological Society of America

VOLUME 30 NUMBER 1

MARCH, 1919

JOSEPH STANLEY-BROWN, EDITOR

PUBLISHED BY THE SOCIETY

MARCH, JUNE, SEPTEMBER, AND DECEMBER

CONTENTS

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA

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Communications should be addressed to The Geological Society of America, care of Florida Avenue and Eckington Place, Washington, D. C., or 77th Street and Central Park, West, New York City.

NOTICE.—In accordance with the rules established by Council, claims for non-receipt of the preceding part of the Bulletin must be sent to the Secretary of the Society within three months of the date of the receipt of this number in order to be filled gratis.

Entered as second-class matter in the Post-Office at Washington, D. C., under the Act of Congress of July 16, 1894

Acceptance for mailing at special rate of postage provided for in Section 1103, Act of October 3, 1917, authorized on July 8, 1918

PRESS OF JUDD & DETWEILER, INC., WASHINGTON, D. C.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 30, PP. 1-142, PLS. 1-6 MARCH 31, 1919

PROCEEDINGS OF THE THIRTY-FIRST ANNUAL MEETING OF THE GEOLOGICAL SOCIETY OF AMERICA, HELD AT BALTIMORE, MARYLAND, DECEMBER 27 AND 28, 1918.

EDMUND OTIS HOVEY, *Secretary*

CONTENTS

Session of Friday, December 27, 1918

The Thirty-first Annual Meeting of the Geological Society of America was held in the rooms of the Department of Geology, Johns Hopkins University, Baltimore, Maryland, on Friday and Saturday, December 27 and 28, 1918, under the presidency of Doctor Whitman Cross, of the United States Geological Survey.

The first general session of the Society was called to order by President Cross at 9.40 o'clock a. m., and the Secretary presented, in printed form, the report of the Council for the year ending November 30, 1918, as follows:

REPORT OF THE COUNCIL

To the Geological Society of America, in thirty-first annual meeting assembled:

The regular annual meeting of the Council was held at St. Louis, Mo., in connection with the meeting of the Society, December 27-29, 1917. A special meeting was held at Washington, D. C., February 28, 1918.

The details of administration for the thirtieth year of the existence of the Society are given in the following reports of the officers:

Secretary's Report

To the Council of the Geological Society of America:

The Secretary's annual report for the year ending November 30, 1918, is as follows:

Meetings.—The proceedings of the annual general meeting of the Society, held at St. Louis, Mo., December 27-29, 1917, have been recorded in volume 29, pages 1-106, of the Bulletin, and of the Paleontological Society, pages 119-154, of the same volume.

Membership.—During the past year the Society has lost six Fellows by death—Charles R. Eastman, G. K. Gilbert, J. D. Irving, P. H. Mell,

C. R. Van Hise, and H. S. Williams. The names of the seventeen Fellows elected at the St. Louis meeting have been added to the printed list. The present enrollment of the Society is 404. Nineteen candidates for Fellowship are before the Society for election and several applications are under consideration by the Council.

Distribution of the Bulletin.—There have been received during the year ten new subscriptions to the Bulletin. Two subscriptions have been canceled—one, only temporarily. The number of volumes sent out to subscribers is now 136. Five volumes are distributed gratis to the Library of Congress, the American Museum of Natural History, and the government geological surveys of the United States, Canada, and Mexico.

The irregular distribution of the Bulletin during the past year has been as follows: Complete volumes sold to the public, 9; sold to Fellows, 9; sent out to supply delinquents, 17, and deficiencies, 1; brochures sold to Fellows, 5; sold to the public, 35; sent out to supply delinquents, 7, and deficiencies, 16. Index to volumes 11-20 sold to the public, 3.

Bulletin sales.—The receipts from subscriptions to and sales of the Bulletin during the past year are shown in the following table:

Bulletin Sales, December 1, 1917–November 30, 1918

	Complete volumes.			Brochures and parts.			Grand total.
	Fellows.	Public.	Total.	Fellows.	Public.	Total.	
Volume 1...	....	....	....	....	....	....	
Volume 2...	....	....	....	....	....	....	
Volume 3...	....	....	....	....	....	....	
Volume 4...	....	....	....	....	....	....	
Volume 5..	....	....	....	....	$0.20	$0.20	$0.20
Volume 6...	....	....	....	......	.50	.50	.50
Volume 7...	....	....	....	....	....	....	
Volume 8...	....	....	....	....	.40	.40	.40
Volume 9...	....	....	....	....	....	....	
Volume 10...	....	....	....	....	....	....	
Volume 11...	....	$7.50	$7.50	....	2.80	2.80	10.30
Volume 12...	....	7.50	7.50	....	....	....	7.50
Volume 13...	....	7.50	7.50	....	1.20	1.20	8.70
Volume 14...	....	7.50	7.50	....	....	....	7.50
Volume 15...	....	7.50	7.50	....	....	....	7.50
Volume 16...	....	7.50	7.50	....	....	....	7.50
Volume 17...	....	....	....	....	....	....	
Volume 18...	....	....	....	....	....	....	
Volume 19...	....	7.50	7.50	....	4.82	4.82	12.32
Volume 20...	$7.50	7.50	15.00	....	3.00	3.00	18.00
Volume 21...	7.50	7.50	15.00	....	2.10	2.10	17.10
Volume 22...	7.50	7.50	15.00	....	....	....	15.00
Volume 23...	7.50	7.50	15.00	....	.40	.40	15.40
Volume 24...	7.50	7.50	15.00	....	....	....	15.00
Volume 25...	7.50	15.00	22.50	....	1.95	1.95	24.45
Volume 26...	7.50	7.50	15.00	....	3.68	3.68	18.68
Volume 27...	15.00	15.00	30.00	$0.90	2.00	2.90	32.90
Volume 28...	....	67.50	67.50	9.40	85.08	94.48	161.98
Volume 29...	....	800.00	800.00	....	....	....	800.00
Volume 30...	....	55.00	55.00	....	....	....	55.00
Total....	$67.50	$1,050.00	$1,117.50	$10.30	$108.13	$118.43	$1,235.93
Index 1–10..	....		....	....	....	....	
Index 11–20..	....	10.50	10.50	....	....	....	10.50
Total ..	$67.50	$1,060.50	$1,128.00	$10.30	$108.13	$118.43	$1,246.43

Receipts for the fiscal year....................................	$1,246.43
Previously reported....................................	22,054.99
Total receipts to date....................................	$23,301.42
Charged, but not yet received on subscription to volume 29........	7.50
Charged, but not yet received on subscription to volume 30........	5.00
Total sales to date....................................	$23,313.92

Expenses.—The following table gives the cost of administration and of Bulletin distribution during the past year:

EXPENDITURE OF SECRETARY'S OFFICE DURING THE FISCAL YEAR ENDING NOVEMBER 30, 1918

Account of Administration

Printing and stationery	$246.87	
Postage	35.49	
Telegrams	7.70	
Express	2.21	
Guest ticket for annual dinner, St. Louis, 1917	3.00	
Telephone and carfare	2.10	
Repairs to rubber stamp	.80	
Porter's fee	.50	
Collection of checks	.20	
Exchange of typewriter	20.00	
Total		$318.87

Account of Bulletin

Express	$29.57	
Postage	17.00	
Telegrams	6.53	
Record book for Bulletin distribution	2.50	
Rubber stamp	1.37	
Telephone	.70	
Printing	32.17	
Collection of checks	2.44	
Clerical and other assistance on inventory	54.00	
Addressograph plates	.98	
Notary's fee	.25	
Total		147.51
Grand total		$466.38

Respectfully submitted, EDMUND OTIS HOVEY,
Secretary.

TREASURER'S REPORT

To the Council of the Geological Society of America:

The Treasurer herewith submits his annual report for the year ending November 30, 1918.

The membership of the Society at the present time is 404, of whom 314 pay annual dues. Seventeen new members were elected at the last annual meeting, 16 of whom qualified. One elected at the 1916 meeting also qualified, making a total of 17 new members. There have been 6 deaths during the present year, 3 Life Members. There was one Life Commutation, making the present list of living Life Members 90. Twenty-six

members are delinquent in the payment of dues—1 for 5 years, 2 for 4 years, 3 for 3 years, 3 for 2 years—and are therefore liable to be dropped from the roll, and 17 for 1 year.

RECEIPTS

Balance in the treasury, December 1, 1917		$1,954.78	
Fellowship fees, 1915 (2)	$20.00		
1916 (2)	20.00		
1917 (12)	120.00		
1918 (289)	2,890.00		
1919 (1)	10.00		
		3,060.00	
Initiation fees (17)		170.00	
Life Commutation (1)		150.00	
Interest on investments (see list of securities)		1,100.00	
Interest on deposits in Baltimore Trust Company		81.67	
Case Library, accessions for 1916		150.00	
Collection charges added to checks		.53	
Received from Secretary:			
Sales of publications	$1,246.43		
Payments of postage and express	14.79		
Collection of checks	.20		
Binding two volumes	4.75		
Author's separates	596.29		
Author's corrections	89.73		
Contribution from author	25.00		
		1,977.19	
			$8,644.17

EXPENDITURES

Secretary's office:			
Administration	$318.87		
Bulletin	147.51		
Salary	1,000.00		
		$1,466.38	
Treasurer's office:			
Expenses	$52.00		
Clerk	100.00		
		152.00	
Publication of Bulletin:			
Printing and paper	$4,391.19		
Engraving	321.07		
Editor's allowance	250.00		
		4,962.26	
Contribution to expenses of H. F. Reid for his mission to France		400.00	
Refund on symposium paper		3.05	
Balance in Baltimore Trust Company		1,660.48	
			$8,644.17

LIST OF SECURITIES

Bonds

Par	
$2,000.	Texas and Pacific Railway Company 1st Mortgage 5's. Due June 1, 2000 (Nos. 11915 and 20892).
1,000.	St. Louis and San Francisco Railroad Company Equipment 5's. Due February 1, 1919 (No. 1171).
2,000.	Fairmont and Clarksburg Traction Company 1st Mortgage 5's. Due October 1, 1938 (Nos. 29 and 30).
3,000.	Chicago Railways Company 1st Mortgage 5's. Due February 1, 1927 (Nos. 20750, 20751, and 45871).
2,000.	Southern Bell Telephone and Telegraph Company 1st Mortgage 5's. Due January 1, 1941 (Nos. M13217 and M3218).
3,000.	United States Steel Corporation 2d Mortgage 5's. Due April 1, 1963 (Nos. 2964, 2974, and 2975).
2,000.	Consolidation Coal Company 1st and Refunding Mortgage 40-year Sinking Fund 5's. Due December 1, 1950 (Nos. 11850 and 11851).
2,000.	American Agricultural Chemical Company 1st Mortgage 5's. Due October 1, 1928 (Nos. 5834 and 6356).

Stocks

10 shares of the capital stock of the Iowa Apartment House Company.
40 shares of the capital stock of the Ontario Apartment House Company.

Respectfully submitted,

EDWARD B. MATHEWS,
Treasurer.

EDITOR'S REPORT

To the Council of the Geological Society of America:

The Editor submits herewith his annual report. The demoralization incident to the war, which has affected adversely so many lines of industry, has been especially severe on the printing business in the city of Washington, where the Society Proceedings are published. It is to be regretted that as a result the issuance of Volume 29 has been delayed greatly. Parts I and II have been completed, and at this writing Part III is being put in page form. The manuscript of Part IV is in the printer's hands. With the gradual resumption of normal business this condition will pass away. The Society may consider itself fortunate to have gotten through the year's printing as well as it has.

The following tables cover statistical data for the twenty-nine volumes thus far issued:

ANALYSIS OF COSTS OF PUBLICATION

Cost.	Average—Vols. 1-25.	Vol. 26.	Vol. 27.	Vol. 28.	Vol. 29.
	pp. 759. pls. 42.	pp. 525. pls. 27.	pp. 757. pls. 30.	pp. 1027 pls. 48.	pp. 698 pls. 22
Letter press	$1,807.41	$1,076.22	$1,684.67	$2,128.15	$1,483.37
Illustrations	327.04	171.69	378.30	484.37	321.07
Paper	....	231.00	416.00	698.00	416.00
Total	$2,134.45	$1,478.91	$2,478.97	$3,310.52	$2,220.44
Average per page	$2.83	$2.81	$3.27	$3.23	$3.18

CLASSIFICATION OF SUBJECT-MATTER

Volume.	Areal geology.	Physical geology.	Glacial geology.	Physiographic geology.	Petrographic geology.	Stratigraphic geology.	Paleontologic geology.	Economic geology.	Official matter.	Memorials.	Unclassified.	Total.
	Number of Pages.											
1	116	137	92	18	83	44	47	-----	60	4	4	593+xii
2	56	110	60	111	52	168	47	9	55	1	7	662+xiv
3	56	41	44	41	32	158	104	-----	61	15	1	541+xii
4	25	134	38	74	52	52	14	-----	47	32	2	458+xii
5	138	135	70	54	28	51	107	-----	71	14	9	665+xii
6	50	111	75	39	71	99	1	-----	63	25	4	538+x
7	38	77	105	53	40	21	123	4	66	28	13	558+x
8	34	50	98	5	43	67	58	14	79	8	----	46+x
9	2	102	138	-----	44	28	64	16	64	12	----	6 0+x
10	35	33	96	37	59	62	68	28	84	27	17	534+xiii
11	65	110	21	10	54	31	188	7	71	60	46	651+xii
12	199	39	55	53	24	98	5	5	70	2	----	538+xi
13	125	17	13	24	28	116	42	4	165	32	29	583+xii
14	48	47	48	59	183	118	22	1	80	14	1	609+xi
15	26	124	3	94	36	267	-----	----	77	17	3	636+x
16	64	111	78	30	102	141	19	-----	67	22	15	636+xiii
17	49	161	41	84	47	294	27	-----	71	9	2	785+xiv
18	16	164	141	5	29	246	5	-----	68	40	3	717+xii
19	106	108	29	66	30	155	32	-----	56	15	20	617+x
20	43	54	35	29	37	45	303	8	60	3	132	749+xiv
21	72	234	75	48	85	70	106	1	111	11	10	823+xvi
22	23	54	28	28	23	403	74	-----	63	49	1	747+xii
23	75	52	126	108	19	145	134	-----	66	32	1	758+xvi
24	18	57	96	57	49	160	106	23	133	53	3	737+xviii
25	34	211	54	32	156	9	175	-----	108	9	22	802+xviii
26	-----	72	23	11	56	90	148	-----	54	44	6	504+xxi
27	1	59	125	31	146	20	271	2	73	24	5	739+xviii
28	25	273	70	69	78	200	55	39	94	110	14	1005+xxii
29	3	107	62	15	127	169	64	-----	73	57	21	679+xix

Respectfully submitted.

JOSEPH STANLEY-BROWN, *Editor*.

December 16, 1918.

The foregoing report is respectfully submitted,

THE COUNCIL.

December 26, 1918.

ELECTION OF AUDITING COMMITTEE

The Society voted to lay the Council report on the table till the following morning session in accordance with custom, and H. B. Kümmel, W. C. Mendenhall, and E. W. Berry were elected an Auditing Committee to examine the Treasurer's accounts and vouchers.

ELECTION OF OFFICERS

The Secretary then announced that on the preceding evening the Council, in accordance with the By-Laws, had canvassed the ballots cast for officers for 1919 and for Fellows and had found the entire list of nominees proposed by the Council to be elected, as follows:

OFFICERS FOR 1919

President:

JOHN C. MERRIAM, Berkeley, California

First Vice-President:

R. A. F. PENROSE, JR., Philadelphia, Pennsylvania

Second Vice-President:

HERBERT E. GREGORY, New Haven, Connecticut

Third Vice-President:

ROBERT T. JACKSON, Boston, Massachusetts

Secretary:

EDMUND OTIS HOVEY, New York City

Treasurer:

EDWARD B. MATHEWS, Baltimore, Maryland

Editor:

JOSEPH STANLEY-BROWN, New York City

Councilors (1919-1921):

WILLIAM S. BAYLEY, Urbana, Illinois
EUGENE WESLEY SHAW, Washington, D. C.

ELECTION OF FELLOWS

Bruce Lawrence Clark, B. S., M. S., Ph. D., Instructor in Paleontology, University of California, Berkeley, California.

Charles Wythe Cooke, A. B., Ph. D., Paleontologist, United States Geological Survey, Washington, D. C.

Roy E. Dickerson, Ph. D., Curator in Paleontology, California Academy of Sciences, Berkeley, California.

Everette Lee De Golyer, A. B., Consulting Geologist, 32 Broadway, New York City.

Frank Fitch Grout, B. S., M. S., Ph. D., Associate Professor, University of Minnesota, Minneapolis, Minnesota.

Edmund Cecil Harder, A. B., M. A., Ph. D., Geologist, United States Geological Survey, Washington, D. C.

Roswell H. Johnson, B. S., M. S., Professor of Geology, University of Pittsburgh, Pittsburgh, Pennsylvania.

Homer Payson Little, A. B., Ph. D., Professor of Geology, Colby College, Waterville, Maine.

Kirtley F. Mather, B. S., Ph. D., Associate Professor of Geology, Queen's University, Kingston, Ontario.

George Charlton Matson, B. S., A. M., Geologist, United States Geological Survey, Washington, D. C.

Euzebio Paulo de Oliveira, Geologist of the Geological Survey of Brazil, Rio de Janeiro, Brazil.

David Bright Reger, A. B., B. S., C. E., Assistant Geologist, West Virginia Geological Survey, Morgantown, West Virginia.

Austin Flint Rogers, A. B., A. M., Ph. D., Associate Professor of Mineralogy and Petrography, Stanford University, California.

Gaillard Sherburne Rogers, A. B., A. M., Ph. D., Geologist, United States Geological Survey, Washington, D. C.

Waldemar T. Schaller, B. S., Ph. D., Chemist, United States Geological Survey, Washington, D. C.

Stuart James Schofield, M. A., B. S., Ph. D., Geologist, Geological Survey of Canada, Ottawa, Canada.

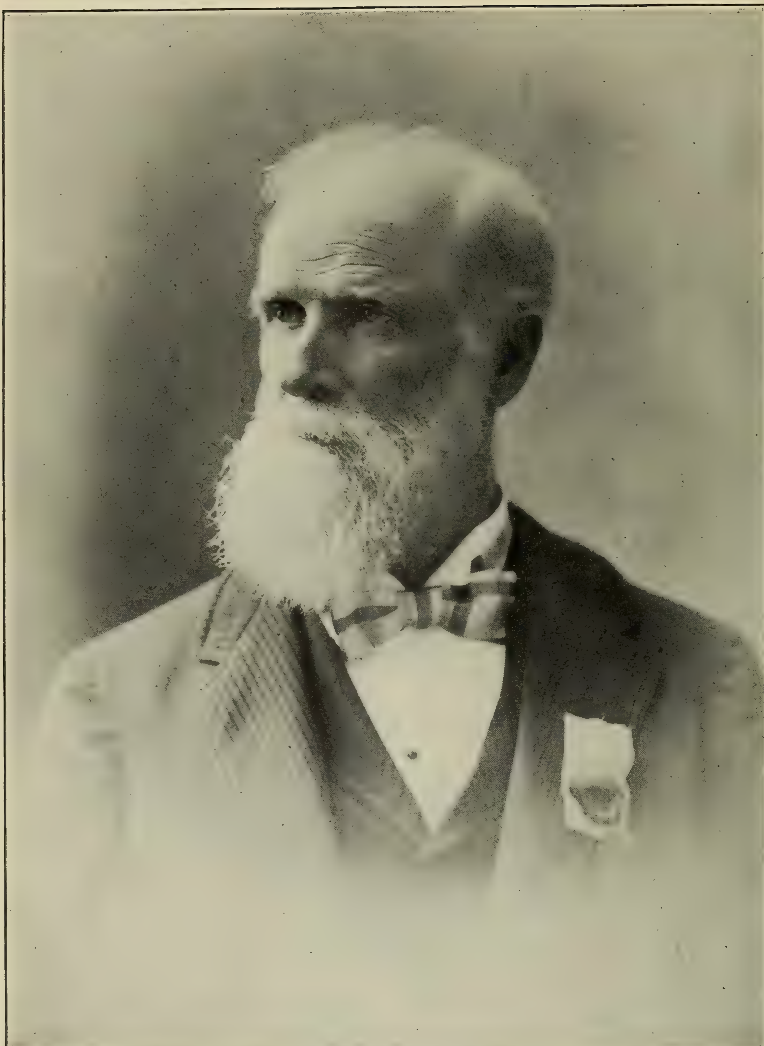
Charles William Shannon, A. B., M. A., Director Oklahoma Geological Survey, Norman, Oklahoma.

Edgar Kirke Soper, B. A., M. A., Instructor in Economic Geology, University of Minnesota, Minneapolis, Minnesota.

Wilber Stout, B. E., Assistant Geologist, Geological Survey of Ohio, Columbus, Ohio.

NECROLOGY

After announcements regarding the order of presentation of the papers listed on and added to the program and concerning certain arrangements of the local committee had been made by the Secretary, the President called for the necrology of the year, six Fellows having been lost by death, namely, Charles R. Eastman, Grove K. Gilbert, John D. Irving, P. H. Mell, Charles R. Van Hise, and Henry S. Williams.



G. C. Broadhead

Memorials of deceased Fellows were presented as follows:

MEMORIAL OF GARLAND CARR BROADHEAD [1]

BY CHARLES R. KEYES

By the recent demise of Garland Carr Broadhead, at the ripe old age of 85 years, the Geological Society loses one of its charter members and the country its only eminent living pioneer in mid-continental geology. Professor Broadhead was the last surviving member of a small coterie of enthusiastic scientists who, in the third quarter of the last century, especially enriched our geological literature by their records of numerous and fundamental observations in the Mississippi Valley.

All members of this distinguished group were protégés of that keen investigator and tireless worker in this field, Dr. David Dale Owen. All adopted the then novel methods and followed the then new precepts of this famous scientist and master-pioneer in earth-study in the New World. The thoroughness of their training and their sound grounding in the advanced phases of that period are amply attested by the fact that after half a century of severest test the results of their efforts stand today without material change.

This same congenial group of mid-western pioneers in science were further particularly characterized by the circumstance that, besides being good geologists, its members were also first-rate, all-around naturalists. The investigations on the rocks were accompanied by full notations on the local weather conditions, the peculiarities of the drainage, the navigability of the streams, and their value as water-powers, the character of the vegetation, and the kinds and uses of the forests, the characters and habits of the birds and animals, the agricultural adaptabilities of the different soils, the kinds and immediate uses of the various minerals, and all like information which was likely to be of service to incoming settlers in a new land. Broadhead had wide knowledge in all of these branches.

By continuing so far beyond the allotted span of life, Professor Broadhead served to acquaint the present generation with the older one and to impress, unconsciously, the former with the scientific spirit and valor of the latter. Voluminous as were the Broadhead writings on strictly geological topics, they were surpassed in number by the accounts on subjects of natural history, anthropology, and local history. The refrain running through all of his work, through all of his courses of instruction at the Missouri State University during the course of his long professorship there, and through his many public lectures, was the adjustment of man's life and efforts to his geological environment.

[1] Manuscript received by the Secretary of the Society, March 10, 1919.

Few of the present generation of geologists were personally acquainted with Professor Broadhead. Those of the generation immediately preceding knew him well. He belonged really to the third generation back. His colleagues were the men who flourished three-quarters of a century ago. His name is firmly linked with those of Owen, Shumard, Norwood, Swallow, Engelmann, Hawn, Meek, and Worthen. His contemporaries in the East were Hall, Conrad, Vanuxem, Hitchcock, the Rodgers, Dana, Lesley, and L. Agassiz. With the passing of Broadhead, the last of the heroic figures in American science makes exit from the geologic stage.

Garland Carr Broadhead was born October 30, 1827, near Charlottesville, Virginia. Nine years afterward the father, Achilles Broadhead, removed with his family to Missouri, settling at Flint Hill, in Saint Charles County, 25 miles north of Saint Louis. Here young Garland received his early education, under tutors at home and at private schools. When he matriculated at the Missouri University, in 1850, he had already shown a strong bent toward mathematics, Latin, and history. Rapid advancement in the first mentioned branch led to his entering the Western Military Institute, one of the famous collegiate schools of that day, located at Drenum Springs, Kentucky. Here he came under the tutelage of Professor Richard Owen, from whom he gained his first inspiration to enter geological fields. At this time General Bushrod R. Johnson held the chair of mathematics and Colonel Williamson the chair of engineering. These distinguished instructors largely determined the future vocation of young Broadhead. Under them he made such rapid progress that when the Chief Engineer of the Missouri Pacific Railroad, then building out of St. Louis, went to Professor Williamson for assistants, Broadhead was selected one of the surveyors. This post he filled with credit to himself and satisfaction to his chief, since in the following year he was promoted to Assistant Engineer, in charge of location lines. In 1857 he was made Resident Engineer of Construction, with headquarters at Hermann. In 1864 Mr. Broadhead married and settled in Pleasant Hill, near Kansas City. With headquarters there, he continued his railroad work in the capacity of Assistant Engineer. Construction work on the Missouri Pacific Railroad was then nearing the Kansas line. This building lasted two years. Later, he was engineer of railways constructing in Kansas, his last work in this field being done in 1880.

The Civil War brought railroad building for a time to a standstill. The strenuous days of that period found Mr. Broadhead helping to preserve the Union. In 1862 he was commissioned Assistant Adjutant General on the staff of General J. B. Henderson. During the same year he was appointed Deputy Collector of Internal Revenue for the First District of

Missouri, which post he occupied for two years, or until the close of the war. Two years later he was appointed by President Johnson as Assessor of Internal Revenue for the Fifth District of Missouri. This office he held until 1868, when he resigned to take up duties on the Illinois Geological Survey. In 1875 he is found preparing the mineral exhibits for the State of Missouri and for the Smithsonian Institution for the Centennial Exposition at Philadelphia. During the exposition he was one of the jurors charged with making awards in the Departments of Geology and Mining. For many years after 1884 Professor Broadhead served as a member on the Missouri River Commission. During a period of five years he was the most active and conscientious member on the Board of Managers of the Bureau of Geology and Mines of Missouri.

Along with his railroad surveying and construction, Mr. Broadhead found ample time to collect fossils and to study rocks. His geological experience along the line of the Missouri Pacific Railroad from Saint Louis to Kansas City gave him an insight into the broad features of the State, such as no observer had yet attained. These were valuable days in the geological field. Dr. George C. Swallow, then State Geologist of Missouri, was early attracted by the results of Broadhead's work. So pleased was the State Geologist that he at once employed him, in 1857, to assist in making a geological reconnaissance along the line of the Southwestern Branch of the Pacific Railroad, now the "Frisco" System. Several publications resulted from this work. Later, as Assistant State Geologist, he investigated the mineral resources of several counties, but the formal reports were not completed before the Civil War put an end to all scientific operations. These county reports, six in number, were published thirteen years afterward, when the Geological Survey of the State was revived, under the headship of Professor Raphael Pumpelly.

In 1868 Mr. Broadhead was appointed by Prof. A. H. Worthen, of Illinois, Assistant State Geologist of that State. During the two years that he was engaged in this capacity he visited nearly every portion of the State. His concise descriptions of the geological features of nine counties are incorporated in volume vi of the Reports of the Illinois Geological Survey. Those parts of these reports which bear directly on the useful minerals were revised and republished in volume iii of the series entitled "Economical Geology of Illinois." Associated with Broadhead on the Illinois work were A. H. Worthen, F. B. Meek, then the leading paleontologist in America; Orestes Saint John, formerly Assistant State Geologist of Iowa and foremost authority in this country on fossil fishes; E. T. Cox, afterward for many years State Geologist of Indiana; Leo Lesquereaux, the most distinguished paleobotanist in Amer-

ica, and Dr. J. S. Newberry, afterward State Geologist of Ohio and a paleontologist of more than national reputation—all names that will be forever associated with the geology of the Mississippi Valley.

In 1871 Mr. Broadhead was recalled to Missouri to serve as Assistant State Geologist under Prof. Raphael Pumpelly, recently appointed director of the revived organization. Besides revising his county reports prepared under the Swallow régime a dozen years before, he devoted much time to an examination of the Coal Measures of the region. The second half of the Pumpelly volume contains the results of these efforts and comprises more than 400 pages profusely illustrated. This report was published in 1873.

When, in the middle of the year 1873, Professor Pumpelly resigned his post as Director of the Missouri Geological Survey, Mr. Broadhead was unanimously chosen in his place as State Geologist by the Board of Managers. With reduced force and depleted funds he entered on his difficult task. The results of the year and a half of investigation are contained in a sumptuous volume of 800 pages, which amply attests the great vigor with which the work was prosecuted. The State Geologist alone contributed 20 chapters to this volume, chiefly detailed reports on the mineral resources of counties.

As Special Agent of the United States Census Bureau, Mr. Broadhead investigated, in 1881, the building stones of Missouri and Kansas. His painstaking report is contained in volume x of the Bureau's publications issued in 1883. In later years Mr. Broadhead contributed important articles to the reports of the Missouri Geological Survey. Two of these deserve special mention. They are entitled "Coal Measures of Missouri," which is a final revision and summary of his work in this field, and the "Ozark Uplift and the Growth of the Missouri Paleozoic," which is also his last word on this topic. The first of these memoirs appears in volume viii and the second in volume xii of the Keyes reports. In the last mentioned volume also appears his "Geology of Boone County," which was written especially for the students in geology in the State University, which is located in that county.

When, in 1887, he was called by the Board of Curators to the Chair of Geology in Missouri University, Professor Broadhead succeeded that venerable colleague of David Dale Owen, Dr. J. G. Norwood, who had held the post for 20 years. For a full decade he performed with signal ability the duties imposed by a rapidly expanding institution. Before his retirement as professor emeritus, in 1897, interest in earth-study had grown in the university until the work of instruction required the time and efforts of three teachers in place of one. Many of Professor Broadhead's students have attained prominence in their chosen line.

Broadhead's youth until he entered college was spent chiefly in Saint Charles County. After leaving school and entering on the practice of his profession, he was located at various points along the line of the new Missouri Pacific Railroad. As construction reached Pleasant Hill, near Kansas City, he made this place his headquarters. Here, in 1864, he married Marion Wallace Wright. Five children were born of this union.

For a period of 25 years he continued to make Pleasant Hill his home—until he was called to a professorial chair in the State University in Columbia, his wife having died in the meanwhile (November 24, 1883). In June, 1890, he was married to Victoria Regina Royall, of Columbia, who survived him. Professor Broadhead, after a brief illness, which did not at first seem to be anything serious, died suddenly on December 12, 1912.

Of Professor Broadhead's scientific work, two features in particular leave enduring impress on the consideration of the geology of the continental interior. His differentiation of the Coal Measures of Missouri and Kansas stands today essentially as he clearly demarkated them nearly half a century ago. Names change, perhaps, but his subdivisions remain practically undisturbed. They withstand every test and many an attack to break them down without success. The classification thus outlined constitutes an integral part of the standard rock scheme for the Carbonic Period of North America. His second notable achievement of more than local bearing is his establishment of the Ozarkian Series, the great succession of Late Cambric rocks found not only typically developed in Missouri, but extended far and wide to the northward in the Upper Mississippi Valley. Both of these generalizations hold high rank. They will ever be connected with his name.

As a man, Professor Broadhead was genial, courteous, and considerate—a thorough Virginian gentleman of the old school. His interests were wide. His detailed knowledge of events and men was astonishing. Few persons in Missouri were so familiar with the ins and outs of local, State, and national politics. He was a mine of valuable information on the early history of the State and the West, and his intimate acquaintance with the historic spots of his State showed clearly how widely and well he had traveled. On local matters relating to geology he was the most helpful man I ever knew.

My first meeting with Professor Broadhead I well remember. Prior to that time for more than a decade there had been frequent interchange of correspondence. It was when I was working up the paleontology of Missouri for the State Geological Survey. Some little time previously, in going over the literature on the subject, I was suddenly confronted

by a great mass of indifferent, unillustrated descriptions of fossils, published by Swallow and by Swallow and Shumard. The descriptions were often so vague and imperfect that I had been more than once tempted to throw the whole mess away and not recognize any of the species. This was already the action of others. As a last resort, I ventured to address a letter to Columbia, inquiring of Professor Broadhead if he could give me any clue to the whereabouts of the old Swallow and Shumard collections. In his reply I learned with unbounded delight that the types and well authenticated specimens were deposited in the university museum, and he had recently spent nearly two years in arranging and preparing the collections for public display. Further, he extended a most cordial invitation to spend a week with him in going over the materials and in visiting and collecting in the original localities, many of which were not far from Columbia. It is needless to say that I lost no time in accepting the invitation.

Before arriving at Columbia I had, of course, fully expected to put up at the hotel. So, on leaving the train, without looking about very much, I hastened to get the hotel bus. Just before reaching that conveyance my grip was grabbed by a stalwart darky and my arm was gripped by a strong hand, that of the Professor himself, whom I was totally unprepared to encounter at this stage of my visit. As we had never met before, I was utterly at loss to understand how, with such unerring instinct, he managed to single me out of that crowd of two or three hundred persons. I had none of the usual accoutrements of a rock-cracker showing. I had no deformities that I knew of by which I might be quickly recognized or that stamped me anything more than a drummer or ordinary traveler.

After first greetings I was hurried into an awaiting carriage and was speeded down to the Broadhead home, where I was informed that I should be expected there to make myself at home during my stay in Columbia. Most of the day was spent in going over the collections at the university in a preliminary way. That evening, after dinner and after making arrangements for the next day for an early 6 o'clock breakfast, preparatory to making an excursion to the Missouri River, we retired to the library. Professor Broadhead was at his best. He was brimful of reminiscences of the older geologists who had worked in the Mississippi Valley, of their petty quarrels over priority, of the pioneer difficulties which they encountered and overcame. His fund of information along these lines seemed inexhaustible, as was his knowledge of the rocks of Missouri and the neighboring States. All this was a veritable bonanza for me, and many a time afterward stood me in good stead when deciding questions in stratigraphy.

On my part, fresh from Johns Hopkins University, with the soul impress of the great Williams still on me, I related to an ever-increasing fire of questions the characteristics and bearings of the new geology: The rock mosaic revealed by the microscope, which startles us with new beauties; the determination of minerals at a glance in thin slices subjected to microscopical examination, when they may be told at a glance as easily as horses and cattle in a meadow; and the then novel conception that minerals and rocks have a life history quite analogous to that of animals, the former distinction between which must now be set aside, seemed to fill him with wonder, of which, however, his acute mind was quick to grasp the philosophic meaning. It was a field which he had never before entered. Conversation lagged not on leadened wings. In the arguments and questions which followed the hours vanished. Time flew on so lightly that the first interruption in the flow of discussion was the sudden appearance at the door of Mrs. Broadhead with the announcement that breakfast was served. Rosy-fingered morn already stood tiptoe on the misty hilltops.

After early repast, with hammer in hand and sandwich in pocket, the old man of seventy and the young man of thirty went rapidly down into the deep labyrinth bounded by high canyon walls. Sunset found them at the end under the beetling cliffs of the Missouri River, with bag and pocket bulging with 50 pounds of treasure. In the little lodging-house at old Rocheport that night we retired early. Although I bade the Professor "Goodnight, sweet Prince, and flights of angels sing thee to thy rest," I fully expected to find him in the morning so stiff and foot-sore and tired out that he should have to be carried home. But no; there was another labyrinth even more enticing than that of the day before. So we returned to Columbia afoot, garnering plentifully of fossils by the way and arriving just in time for a fine chicken dinner à la Southern.

The time spent on the Swallow and Shumard collections was fully occupied. Copious notes on identifications and comparisons were taken with the main theme in mind of later making complete descriptions and illustrations. Before this could be accomplished the central building of the university, which contained the collections, was completely destroyed by fire. I know of no other notes ever being taken on these unique collections, and the opportunity satisfactorily to straighten out the moot questions concerning the original unfigured descriptions was lost for all time.

The diverse character and wide range of Professor Broadhead's efforts in geology are best indicated by the titles of his publications.

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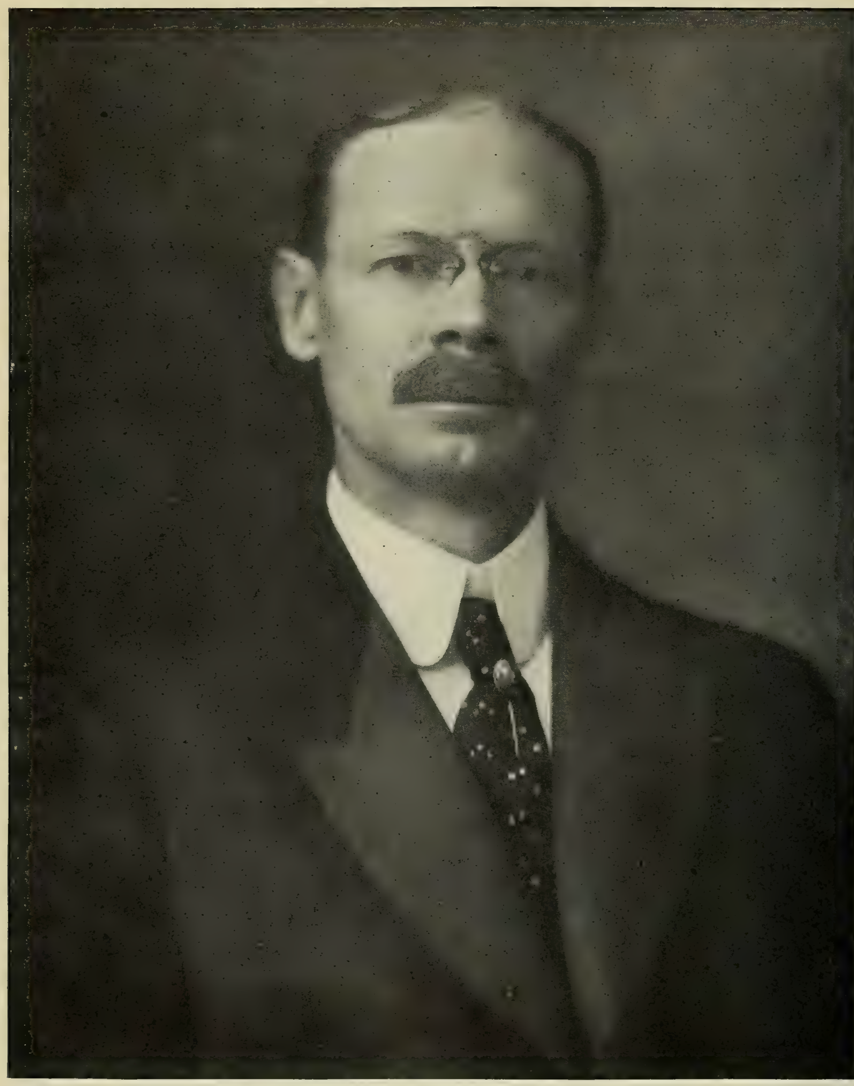

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C. R. Eastman.

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MEMORIAL OF CHARLES ROCHESTER EASTMAN [1]

BY BASHFORD DEAN

Charles Rochester Eastman, long-time member of the Geological Society and active in its counsels, died at Long Beach, New York, September 27, 1918. At the outbreak of the war he entered the service of the United States; he was given a peculiarly exacting task and he over-exerted himself. It came about that he contracted influenza and, leaving his post in Washington, he retired for a brief rest by the sea. It appears that on the night of his death he left the hotel after dinner, took a walk on the boardwalk, and fell through a broken portion of the pier into the surf. Stunned by the fall, he was drawn into deeper water and drowned.

[1] A similar notice, but less extended, appeared in Science, February 7, 1919.

Doctor Eastman is one of the few zoologists on this side of the Atlantic who devoted their lives to the study of ancient fishes, which, for the rest, concerns not a few of the greatest problems of the vertebrates; and his services to this field will cause his name to be associated with those of Agassiz the elder, Cope, Newberry, and Leidy. His publications dealing with paleichthyology include over a hundred memoirs, some of which rank among the most scholarly and accurate in their field.

Doctor Eastman was born at Cedar Rapids, Iowa, on June 5, 1868, son of Austin Vitruvius Eastman and Mary Scoville. He graduated from Harvard in 1891, studied at Johns Hopkins, thereafter in the University of Munich, where he took his doctorate in 1894; he worked with Prof. Karl von Zittel, whose laboratory then attracted a number of young American paleontologists. Here, as Eastman's interests already centered in fossil fishes, he was given the only material for research which the German university had at hand—a mass of detached teeth of a chalk measure shark—not attractive material, to say the least; but the young investigator attacked it with energy and soon gathered the data for a successful thesis. He was next given a post at Harvard, where, in the Museum of Comparative Zoology, under the mantle of Louis Agassiz, he reviewed the collections of early fishes and found much material for publication. He soon became interested in the Devonian fossils of the Agassiz collection, which he found shed light on the rich finds from the Middle West, then being described by Doctor Newberry. Eastman's imagination was especially touched by the range and character of "placoderms" as the dominant group of Devonian times, and, like many another worker, he set himself to solve the puzzles of their lines of evolution and of their kinship to modern fishes. Hence he sought actively for more extensive and better preserved material on which to base his findings. The best collecting ground for these American forms was in Ohio, and throughout this region Eastman soon learned to know the fossil hunters and their collections. His studies on these forms soon spread over wider fields and became well-nigh encyclopædic: he had the entire Devonian fish fauna at his finger-tips, literally; and if Eastman were sought for at this time, he would have been found at the top of the Agassiz Museum, in the center of a labyrinth made up of tiers of great trays of fossils, and the visitor would come away with the impression that there was something almost uncanny in the skill with which Eastman could call up out of the mud-colored shales these primeval creatures, for their *membra disjuncta* would come together so distinctly that one could almost picture the fish coming to life in its tray!

From the study of placoderms, Eastman's studies extended naturally to the contemporary lung-fishes and ganoids, and to our knowledge of these early forms he made numerous contributions. Now and again he would hark back to the group of sharks, trying ever to bring order into this primitive and difficult group. Port Jackson sharks, with their curiously modified dentition, which enabled them to crush the shells of shell-fish, suggested new lines of evolutional changes, and his work on these forms from Illinois, Iowa, Missouri, Kansas, and Nebraska showed new sequences and enabled him to fill out the gaps in their history. Certain of these early sharks became so similar to lung-fishes in their dentition that on this evidence alone the two great groups of fishes might readily have been merged.

During the last decade of his work Eastman's attention was drawn more closely to types of modern fishes. This was perhaps due to the fact that he had been able to bring to this country the famous collection of a Belgian paleontologist, de Bayet, and install it in the Carnegie Museum at Pittsburgh. On the fishes of this collection, especially those from northern Italy (Monte Bolca), he published a number of beautiful memoirs.

In matters relating to the phylogeny of fishes, Eastman was conservative. Thus, following Smith Woodward, he maintained that the group of placoderms which the latter defined as *Arthrodira* was definitely related to primitive lung-fishes. He had little sympathy with those who believed that they had solved the riddle of Tremataspis and Bothriolepis by associating them with arthropods. As a systematist, Eastman was thorough, and the forms which he described will rarely need revision.

No one can recall Doctor Eastman without bringing to mind his keen appreciation of ancient literature. He read the classical texts fluently, and Aristotle and Pliny had to him the interest of modern authors. Perhaps he knew them and their kind better than did any living paleontologist. For bibliographical work, Eastman had ever a distinct leaning, for to know what others had done in a definite field was only an honest beginning of any research. It was this interest which led him to accept the invitation of the America Museum of Natural History to undertake the editorship of a Bibliography of Fishes which the Museum was engaged in publishing, and it was under his supervision that the first two volumes of this work appeared—ever to lighten the labors of workers in this field.

One may record, finally, the posts held by Doctor Eastman: Instructor in Paleontology and Historical Geology at Harvard, 1894-95, and at Radcliffe College, 1895-97. Curator in charge of Vertebrate Paleontology at Harvard Museum, 1895-1910.

1910-14, Professor of Paleontology at University of Pittsburgh and Curator at Carnegie Museum, conducting investigation as Research Associate of Natural History.

1914, United States National Museum, Washington. Assistant Geologist, New England Division, United States Geological Survey; also special work connected with the geological surveys of Iowa, New York, Maryland, Connecticut, and New Jersey.

Doctor Eastman married, June 27, 1892, Caroline Amelia Clark, daughter of Alvan Clark, the well known maker of telescopes. His son, Alvan Clark Eastman, was born March 10, 1894.

Bibliography

A list of Doctor Eastman's publications on the subject of fishes is given herewith. (See Dean and Eastman's "Bibliography of Fishes.") References to his other writings occur in the Annual Report of the Museum of Comparative Zoology, Harvard College, 1895-1909; Johns Hopkins University Circular, 1913, number 10, pages 36-38.

Mrs. H. J. Volker has recently reviewed the papers of Doctor Eastman, and summarizes his systematic contributions as follows:

New families:
- Astraspidæ
- Peripristidæ
- Pholidophoridæ

New genera:
- Belemnacanthus
- Campyloprion
- Dinomylostoma
- Eobothus
- Eolabroides
- Gallinuloides
- Gillidia
- Histionotophorus
- Palæophichthys
- Parafundulus
- Parathrissops
- Phlyctænacanthus
- Protitanichthys
- Synthetodus
- Tamiobatis

New species:
- Acanthodes beecheri; marshi
- Ameiurus primævus
- Amiopsis (?) dartoni
- Anguilla branchiostegalis
- Asterolepis clarkei
- Asthenocormus retrodorsalis

- Belemnacanthus giganteus
- Blochius moorheadi
- Bothriolepis coloradensis

- Campyloprion annectans
- Caranx primævus
- Carcharias collata; incidens
- Cestracion zitteli
- Chanoides leptostea
- Cladodus aculeata; prototypus; urbs-ludovici
- Cœlacanthus exiguus; welleri
- Cœlogaster analis
- Conchodus variabilis
- Ctenacanthus acutus; decussatus; longinodosus; lucasi; solidus; venustus

- Dicrenodus texanus
- Dinichthys dolichocephalus; livonicus; pelmensis; pustulosus; trautscholdi
- Diplodus priscus; striatus

Diplomystus goodi
Dipterus calvini; costatus; digitatus; mordax; pectinatus; uddeni

Elonichthys disjunctus; perpennatus
Eomyrus formossimus; interspinalis
Erismacanthus barbatus; formosus

Fissodus dentatus

Galeocerdo triqueter
Glyptaspis abbreviata
Gyracanthus primævus

Harpacanthus procumbens
Helodus comptus; incisus
Histionotus reclinis
Homacanthus acinaciformis; delicatulus
Homœolepis suborbiculata

Janassa maxima; unguicula

Lepidotus ovatus; walcotti

Machæracanthus longævus
Macrosemius dorsalis
Mene novæ-hispaniæ
Myliobatis frangens
Mylostoma newberryi

Notagogus decoratus; minutus; ornatus

Oenoscopus elongatus
Onchus rectus
Oracanthus triangularis
Orodus intermedius

Palæophichthys parvulus
Parafundulus nevadensis
Parathrissops furcatus
Phlyctænacanthus telleri
Phœbodus dens-neptuni; knightianus
Pholidophorus americanus
Phyllodus hipparionyx
Physonemus hamus-piscatorius; pandatus
Platinx intermedius
Polyrhizodus grandis
Priscacara dartoni
Propterus conidens
Protitanichthys fossatus
Ptyctodus compressus; ferox; panderi; predator; punctatus
Pygæus agassizii

Rhadinichthys deani
Rhynchodus major; pertenuis; rostratus

Sagenodus cristatus; pertenuis
Sauropsis curtus; depressus
Squatina minor; occidentalis
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Streblodus angustus
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Synthetodus calvini

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Urosphen attenuata

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J. D. Irving

MEMORIAL OF JOHN DUER IRVING [1]

BY JAMES F. KEMP

Amid the widespread feelings of relief, albeit a bit apprehensive, with which the cessation of hostilities has been received, we turn aside to remember one who made, while yet the war went on, the supreme sacrifice in the service of his country. Just before the first of August the cable brought the news that John Duer Irving, Captain in the Eleventh Regiment of United States Engineers ("The Fighting Engineers," as they have been called ever since the first British drive at Cambrai), Professor of Economic Geology in Yale University, and Fellow in this Society since 1905, had passed away while on duty with his regiment at the Flanders front. The Geological Society thus lost one who had been often at its meetings, and who was widely known as one of the most fruitful and stimulating workers on the problems presented by ore deposits and other useful minerals.

John Duer Irving was born in Madison, Wisconsin, August 18, 1874, and was the oldest child of Roland Duer Irving, to whose work in the fifteen years following Lake Superior geology owes so much. Roland Irving was at the time Professor of Geology, Mineralogy, and Metallurgy in the University of Wisconsin. John Irving, the son, passed his boyhood in the home where his father was preparing Monograph V of the United States Geological Survey on the Copper-bearing Rocks of Lake Superior, and was beginning the studies and contributions on the Gogebic Range, which were completed after his death by his friend and colleague, Charles R. Van Hise. Not only was John Irving's father busy with the Keweenawan rocks, but the skillful hand of his mother was preparing with her brush and pencil the beautiful colored plates with which their microscopic characters are illustrated. After the loss of Prof. Roland Irving, Mrs. Irving moved, with her children, to New York among her kinsfolk, and John was prepared for Columbia College, the alma mater of his father, grandfather, and great-grandfather, the last named a brother of Washington Irving. John gave special attention to geology during his undergraduate days, passed the vacation following his junior year, with one of Prof. Henry F. Osborn's parties from the American Museum of Natural History, in the Tertiary beds of the Uintas, and graduated in 1896.

Having decided to follow his father's footsteps in the calling of geologist, he spent the summer with the writer in the eastern Adirondacks and

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[1] In the absence of the author, his abstract was read before the Society December 27, 1918, by C. P. Berkey.

Manuscript received by the Secretary of the Society January 6, 1919.

entered on his graduate study in the autumn. During the vacation of 1897 he was a member of Dr. Whitman Cross's party in the San Juan region of Colorado, and in the open season of the next year took up the field-work for his doctorate in the northern Black Hills of South Dakota. In June, 1899, he received his Ph. D., and having passed with high credit the civil-service examinations for the United States Geological Survey, he received an appointment and was sent back to the Black Hills, where he studied the ore deposits under the general oversight of Dr. S. F. Emmons. The appended bibliography will show the printed results; but the association began at this time with Doctor Emmons later developed into much work together, and ultimately made of the younger man the chief assistant, and finally the literary and scientific executor of the older. Years afterward, when Doctor Emmons passed away, leaving in fragmentary and uncompleted state the great new monograph on Leadville, John Irving finished the manuscript and forwarded it to the Survey ready for the printer.

The field experience which Irving had gained in one Eastern and three Western States before he had been three years out of college was later amplified by work in many parts of the country. He assisted F. L. Ransome in the Globe district of Arizona; worked with J. M. Boutwell in the Park City district of Utah; prepared with W. H. Emmons the economic geology of the Needle Mountains quadrangle, Colorado; with Whitman Cross and Ernest Howe the description of the Ouray quadrangle; with S. F. Emmons the Bulletin on the Downtown District of Leadville, and with Howland Bancroft the Bulletin on the Geology and Ore Deposits near Lake City. He also did mapping of coal-bearing quadrangles in Indiana with M. L. Fuller and in southwestern Pennsylvania with M. R. Campbell.

These field experiences with parties of the United States Geological Survey lasted long after he had taken up teaching and were chiefly performed during the summer vacations. The desire to teach and to come in close personal and formative relations with younger men grew stronger and stronger in Doctor Irving and led him, in 1903, to begin his teaching career as substitute for Prof. Wilbur C. Knight in the University of Wyoming, when the latter was granted a year's leave of absence. The following year a call to be Assistant Professor at Lehigh University took him to South Bethlehem, and two years later he was promoted to the full chair. In 1907 he was called to be Professor of Economic Geology in the Sheffield Scientific School of Yale and shared in developing the mining courses made possible by the gift of the Hammond Laboratory. In this

professorship he continued up to the time of his death, as he was on leave of absence from the university while serving with his regiment.

During his years of teaching Doctor Irving amplified his already exceptionally extended field experience by work in mining geology of a professional nature, and in this way was enabled to visit Alaska, Montana, and Idaho. He attended the International Geological Congress in Stockholm in 1910, and thus enjoyed the exceptional opportunities afforded by the Congress to see the ore deposits of Sweden. While in Europe for the Congress, he traveled also on the continent with his friend Waldemar Lindgren, with whom he prepared a paper on Rammelsberg, as the result of their joint visit. Thus in his work as teacher, John Irving drew on a wide and varied experience and on extended personal observation made both as scientific man and as engineer. To an exceptional degree, therefore, he was able to meet the requirements of a professorship in a technical school and of the courses in the applications of geology, which are now much sought and are among the most important offered in the curricula of our universities. In the inevitable vocational developments of college and university instruction which will accompany the reorganization after the upheaval of the war he will be greatly missed, since he combined in high degree the ideals of accurate and unselfish work with the good sense of the engineer.

In 1905, while John Irving was yet at work at Lehigh University, the plan was developed of establishing a magazine which might be the special means of expression and record for the vigorous young school of American students of ore deposits and applied geology, which had then become a marked feature of our scientific life. We gathered a little band ready to maintain such a journal through what was anticipated would be two or three years of financial struggle for self-support. John Irving was chosen as editor, and to his untiring efforts, ably aided by the unselfish work of W. S. Bayley as business manager, we chiefly owe the thirteen volumes of this valuable and interesting journal. No one can turn its pages without a feeling of admiration for the succession of contributions which it contains. As we look the volume over, we note also the subjects which especially appealed to the active and philosophical mind of the editor. His work in the mining districts emphasized the importance of ore-shoots and local places of value in veins, and he seeks to classify and systematize their causes. He is again impressed with the importance of a comprehensive study of special problems wherever one particular case of them may be illustrated, as contrasted with the generally localized investigations carried on by one individual. His extended experience at Leadville in the mines, where S. F. Emmons made the illuminating application of

the conceptions of replacement, leads him to seek criteria whereby replacement bodies may be identified.

And then, while in the active exercise of his many useful activities, came the war of German aggression. As its early months passed, and every thinking American realized that his country could not maintain much longer its supine attitude, while common decency as well as civilized life hung in the balance, I know from intimate talks with John Irving that he became convinced that he should respond in person to the call. Being unmarried, he felt it his duty to go to Plattsburg, although he was beyond forty years of age. He entered the officers' training camp in the summer of 1916 and took up its routine earnestly and seriously. He passed through the grades of non-commissioned officer, and when the camp closed entered his name as one available for service if conditions called for him. The following spring the anticipated conditions materialized. He was commissioned captain, was assigned to the Eleventh Regiment of Engineers, and was granted leave of absence by the authorities of Yale. He sailed for France in July, 1917. We are permitted by the censor to know that he was early engaged in railway construction and worked at top speed to maintain these arteries of supply for the army in full activity. His duties brought him under shell-fire, and he learned to keep his nerve under these trying conditions. Later, when dug-outs, tunneling, and the exploding of mines beneath the enemy's works achieved such importance, he was transferred to the Engineers' school at headquarters, and was busy with a seemingly endless procession of classes to be instructed in the rudiments of mining engineering. His letters show that the calls were hard, exacting, and exhausting. He returned again to the front, met a class or two of engineers there, was stricken with the Spanish influenza, and developed pneumonia, against which he had not the strength to rally, although every resource of modern medicine was used to aid him. July 20 his name was added to the honor roll.

John Duer Irving was a man of the highest ideals of service, whether the service was rendered to his students, his university, or his country. His duties were discharged faithfully and with a deep sense of responsibility. The magazine *Economic Geology* was a labor of love. The time of Professor Irving was never so valuable but that a student could command advice and guidance. The full strength and more of Captain Irving was given to his country. As a geologist his work is marked by painstaking care and a conscientious ambition for accuracy. He was given to thinking out his problems to a carefully grounded solution. In literary expression he is clear and easily understood, and in these respects

maintained the high traditions of his family, which furnished this country with one of its first really great men of letters.

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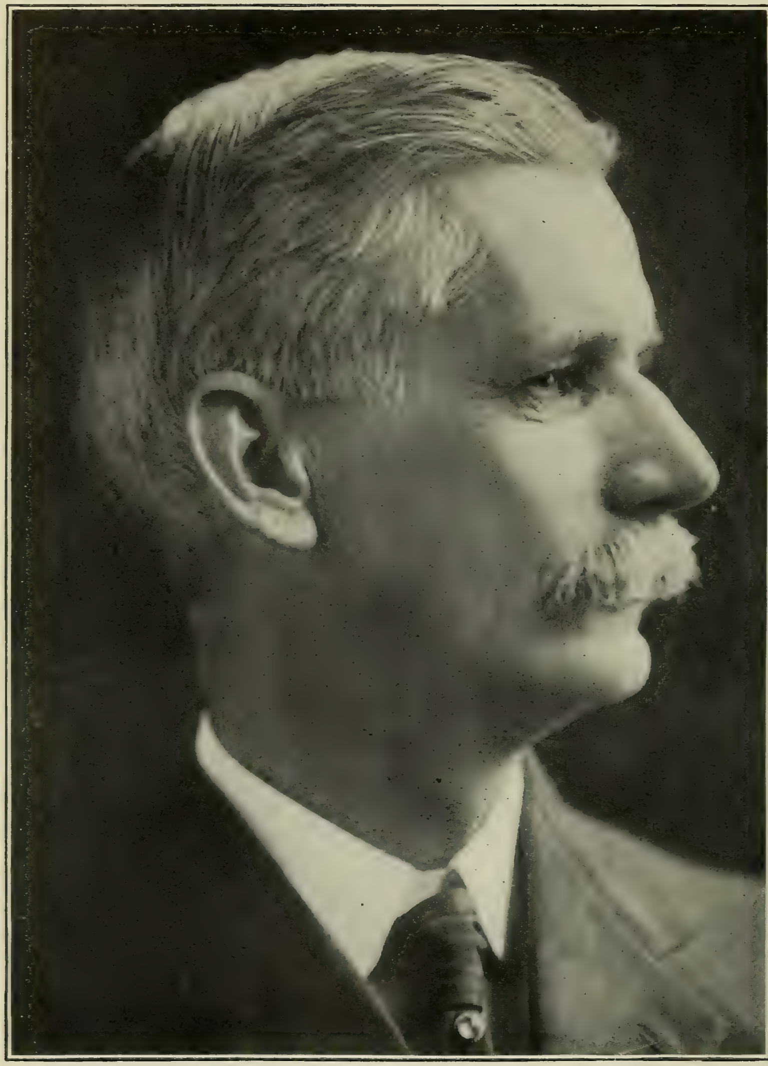


P. H. Mell

MEMORIAL OF PATRICK HUES MELL [1]

BY FRED H. H. CALHOUN

Patrick Hues Mell, son of Patrick Hues and Lurene Howard (Cooper) Mell, was born in Penfield, Georgia, May 24, 1850, and died in Fredericksburg, Virginia, October 12, 1918.

His father, a Baptist preacher, was for many years a professor at Mercer University, and during the last ten years of his life was Chancellor of the University of Georgia. Thus Doctor Mell was raised in a college atmosphere. Entering the University of Georgia in 1866, he completed every course in that institution, graduating successively with the degree of A. B. in 1871, C. E. in 1872, and M. E. in 1873, the mining course being then offered for the first time. In 1880 he received his Ph. D. from the same institution.

Very early in life he showed an aptitude for the natural sciences. As a boy he was fond of taking long excursions in the woods, and at an early age had made himself familiar with the plants and minerals of the South.

The first few months after his graduation, in 1873, Doctor Mell spent as a consulting mining engineer. In 1874 the Georgia State Agricultural Department was organized, this being one of the first in the South, and Doctor Mell was made State Chemist. In this capacity he analyzed soils and commercial fertilizers, which were then just being put on the market. They were greatly adulterated, and the officials of this new department had a difficult time between the necessity of exposing poor fertilizers and the desire to popularize the new department among the people and politicians.

In 1875 he married Miss Annie White, of Athens. She has always been deeply interested in his work and has proved a sympathetic and helpful companion during the many years of their life together.

Under the confinement of the laboratory, Doctor Mell's health broke down, and in 1877 he resigned as State Chemist to go into open-air life. As a mining engineer he tramped and rode horseback from North Carolina to Alabama. Those were stage-coach days and the mountains were full of bandits; but though he always went unarmed he was never molested. During this period, as correspondent of the *Engineering and Mining Journal*, he wrote, at the request of the editors, a series of articles on the clays, gold, and corundum of the unknown South. In the summer of 1878 he attended a State Industrial Convention in Alabama, where he carried a collection of specimens of Alabama minerals, with

[1] The author's abstract of this memorial was read before the Society December 27, 1918, by the Secretary, in the absence of the author.

maps of their location. This attracted much attention. The President of the Agricultural and Mechanical College of Alabama was present, and was so pleased with the exhibit that he tendered Doctor Mell the chair of Natural History at Auburn. Having regained his health, he went to Auburn in the fall of 1878. Yet he always looked back on those eighteen months in the mountains as perhaps the fullest and happiest of his life, and later expressed regret that he had not given his entire time to geological work, as that was his favorite subject. He often confessed to me that he believed he would have made a greater reputation for himself as a geologist than as a college president.

For some years he spent all of his vacations prospecting in the mountains or at Claiborne, Alabama, where he collected the famous Claiborne fossils from the bluffs by the river. He arranged collections for exchange, and in this way acquired many valuable specimens for the museum. His collection at Auburn, which was the finest in the South, received the highest commendation from experts from all parts of the country. When the college building burned in June of 1887, he was away, and the telegram, "Nothing saved of all your valuable collection," so depressed him that he never had the heart to replace it, though he always aided in building up the museum. Doctor Mell had scientific correspondents all over the world. Among these was Jacques De Morgan, then a young man, afterward the great Assyrian and Egyptian explorer.

In 1884, when the State Weather Service was started, Doctor Mell was asked to take charge of the work for Georgia, Florida, and Alabama, with his office at Auburn. When the bureaus were formed in the separate States, he retained the direction of the one at Auburn for Alabama, doing this in addition to his college work. This position he kept until 1893. The system of weather signals now used by the United States Weather Bureau was his invention. He was repeatedly asked by the officials in Washington to allow himself to be made Chief of the Weather Bureau, but he always declined.

From 1898 to 1902 he was connected with the Alabama Experiment Station. He carried on many valuable experiments in cotton-breeding during these years. He was asked to arrange the cotton exhibit of the Southern States for the Paris Exposition in 1900.

While at Alabama he was thrice tempted to leave his scientific work for executive. He declined the presidency of Mercer University in 1893 and of the North Georgia Agricultural College in 1897, but in 1902 he at last yielded to the insistent demands for his services in this other capacity, and became President of Clemson College, South Carolina, which position he held for eight years. It was as a college president that

I knew him, and I have most grateful recollections of him in that capacity and of his interested helpfulness to me, a young professor. He was essentially a kindly man in all of his relations, both official and personal, and his courtesy was as great to the humblest member of his faculty as to one of highest rank.

Doctor and Mrs. Mell were extremely hospitable and their home was the center of all college activities. Doctor Mell possessed to an unusual degree the faculty of leaving his official cares with his desk—a quality which enabled his guests to know the man more intimately.

In 1910 he resigned the presidency of Clemson College and retired to a home in Atlanta, expecting to enjoy a well-earned rest. But even here duties sought him out, and his last years were spent in the service of his church, on the Baptist Home Mission Board.

In thinking over the events of Doctor Mell's life, one is impressed with the fact that he was a pioneer in so many lines. At the time when he began teaching, the realization of the necessity for specialization in different branches of science was, especially in the South, just being recognized. Instead of expecting a "science teacher" to know all branches of science, the colleges were awakening to the fact that a man's whole life is too short to master any one. Thus we see Doctor Mell, time after time, at the parting of the ways, when he must choose between two branches of a subject both of which attracted him. He had a part in the growth of mining engineering in the South, in the establishment of State departments of agriculture, of experiment stations, of the Weather Service, and the important development of the agricultural and mechanical colleges of the South.

I quote now from a letter to me from Dr. George Petrie, who was closely associated with him at Auburn before I knew him. Doctor Petrie says:

"About thirty years ago I arrived in Auburn to begin my work as a teacher in what was then the Agricultural and Mechanical College of Alabama. It was my first job of teaching. I had my anxious moments and, to tell the truth, I was dreadfully homesick. Out of pure kindness, Professor Mell and his wife took me in their home. It was one of the best things that ever befell me. From that day until he died it was my pleasure to count him as a personal friend.

"As I look back over those years of close contact, much of the time as a colleague, I begin to realize what a strong influence he had on all of us who were near him and on the students who were in his classes. That strong personal influence was the key to his success. He was a very modest man, and an extremely courteous one, but his influence was not to be resisted. In this he was a fine type of the Southern professor of the old days. He was not a mere specialist; he was a scientist with broad sympathies and an attractive

personality. He loved his work and his enthusiasm was contagious. He was never too busy to help a friend, never too worried to listen to another's troubles, or too absorbed to sympathize with him. This was the personal touch which endeared him to his friends. To him human life was the great thing, and even his beloved science got its value and its charm for him from the light that it threw on life and on the world we live in.

"It seemed to me that he was always busy with some piece of scientific research. Early in the morning he was at his office or in his laboratory working. The afternoon found him still there, while the rest of us were out for walks or sport. Often at night the last that I saw of him he was sitting in his study, half curtained off from the sitting room, still working, working. That was in the days before modern processes had simplified such labor. He made his own experiments; he corrected his own proof; he made the illustrations with his own camera or on his own drawing board. And he did all this in moments snatched from days already filled with college duties.

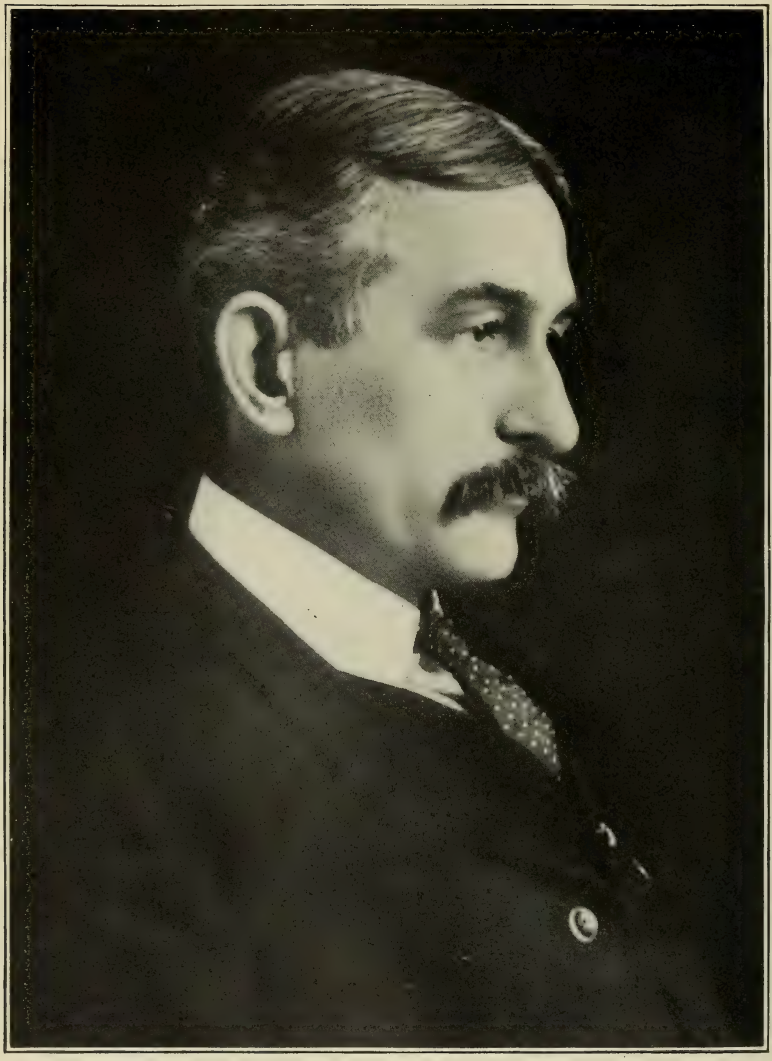
"He was a kinsman and admirer of the famous Le Conte. I suppose it was from him that he got his first enthusiasm for geology. Le Conte's Geology always had a favorite place on his desk and a tender spot in his heart, although he did not agree with all of Le Conte's conclusions.

"Botany was, next to geology, his favorite study. I remember vividly the infinite care and pains that he put on a study of the cotton plant. It was, if I am not mistaken, made for the Paris Exposition. He was then Director of our Experiment Station, and I believe that some other members collaborated with him in their particular fields. The publication attracted wide attention; but what impressed me was his method of work—his care in cross-breeding, the beautiful microscopic plates that he made to illustrate the results in the fiber, the careful photography of plants, bolls, and microscopic results, the elaborate tables, and, above all else, the pleasure that he took in his work. That always struck me as characteristic of the man—his delight in his work. It did not seem to be drudgery to him. He worked, not grimly, as some do, but in fine humor. He was blessed with a keen sense of fun, and he was able to joke when things went wrong.

"From this steady labor he found relaxation among his friends. I do not think he cared for society in any formal sense, but in his own home he was the prince of good fellows. Real hospitality went deep down into the marrow of his bones. He was genial, unreserved, charming. He and his wife were fond of music. They sang the old-time songs that were rich in sentiment and melody, and his flute was full of mocking-birds and Southern moonlight.

"Devoted as he was to scientific research, I think he regarded teaching as, to use a fine old phrase, his calling. It was not just a way to make a living. It was a high and noble profession, with great opportunities and equally great responsibilities."

Doctor Mell was a member of Kappa Alpha and Phi Beta Kappa fraternities. He became a Fellow in the Geological Society of America in 1889. He belonged to the American Association for the Advancement of Science, the Southern, South Carolina, and Alabama historical societies, the National Geographic Society, and the Sons of Confederate Veterans.



Henry S. Williams

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He was the author of the following publications:

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Wild Grasses of Alabama.
Microscopic Study of the Cotton Plant.
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Life of Patrick Hues Mell, Sr., LL. D.
Botanical Laboratory Guide.
Revision of Mell's Parliamentary Practice.
Revision of White's Gardening for the South.
Biological Laboratory Methods.
Contributions of the South in Building of Nation.
Administrative Methods in American Colleges.
Industrial Education and its Value to the South.

MEMORIAL OF HENRY SHALER WILLIAMS [1]

BY HERDMAN F. CLELAND

Henry Shaler Williams was born March 6, 1847, at Ithaca, New York, and in this region, with its deep, picturesque gorges and beautiful lake, he spent his youth and the greater part of his mature years. The interest excited by the fossils which he found as a boy in the fossiliferous shales and sandstones of the ravines and gorges about Ithaca probably determined his choice of a profession, as they later furnished him with the key which enabled him to unlock some of the mysteries of stratigraphy. From these he also learned the precise methods of stratigraphy for which he will long be known.

Professor Williams sprang from colonial stock. The Williams' progenitor settled at Saybrook, Connecticut, in 1640, and his descendants, in the direct line, remained in that State until the father of the subject of this sketch moved to Ithaca, New York. On his mother's side we find that the family, the Hardy's, came to America shortly before the Revolutionary War.

He prepared for the Sheffield Scientific School at Ithaca Academy and graduated from Yale in the class of 1868. His popularity as a student is shown by his election to the Psi Upsilon Fraternity. After graduation,

[1] In the absence of the author, an oral tribute to the deceased was paid by Whitman Cross before the Society on December 27, 1918.

[1] Read before the Society December 27, 1918.

Manuscript received by the Secretary of the Society December 28, 1918.

he continued at Yale as assistant in paleontology and graduate student in geology and zoology and received his doctorate in 1871. Upon completing his graduate work he taught a year at Transylvania College, then known as Kentucky University.

The years between 1872 and 1880 were spent in business in Ithaca at the earnest request of his father who wished all of his sons to cooperate with him in the banking and mercantile enterprises which he had founded. He spoke to me at one time of these years spent in business as very unhappy ones because his interests were in scholarly pursuits and not in the mere making and accumulating of money. One should not conclude from this statement, however, that he lacked business ability. His analytical mind and the conservative training which he received from his father enabled him to exercise good judgment in business matters, and he left to his children a fortune somewhat larger than that which he had inherited.

In 1879 he was elected Assistant Professor of Geology at Cornell University—a title which was changed to Professor of Paleontology in 1880. In 1884 he was promoted to a full professorship, which, in 1886, was made to include geology.

In 1892 the high regard in which he was held by Prof. James D. Dana, who was attracted to him as a student and who had closely followed his work as an investigator, is shown by his appointment, at the personal request of Dana, to the Silliman Professorship of Geology, which Professor Dana had so long held. This appointment was very gratifying to Williams not only because it was a recognition of his scientific work but also because of the honor of the appointment to that chair. His stay at Yale, however, was not as pleasant as he had anticipated, and twelve years later he returned to Cornell University as Professor of Geology and Director of the Geological Museum. Here he remained in the region whose study gained for him recognition as one of America's foremost paleontologists until, on reaching the retiring age in 1912, he became Professor Emeritus. The last two years of his life were spent in Cuba, where he was much interested in the development of oil on a son's property. He died in Havana of pleurisy July 30, 1918.

Henry Shaler Williams began his scientific studies at a time when unusual interest was being aroused in geology and paleontology. Some of James Hall's notable monographs on the paleontology of New York State had already appeared, and the year before he graduated from Yale (1868) the report on the Upper Helderberg, Hamilton, Portage, and Chemung was published in which are described the fossils from the for-

mations along the shores of Cayuga Lake, at the head of which young Williams lived. It is possible that had not this report been published when it was Williams would not have become a paleontologist. Many of the superb earlier geological reports of Illinois, Ohio, and Pennsylvania were published at this time or had but recently appeared. Cope was describing his wonderful discoveries of fossil fishes, reptiles, and mammals from the West, and Marsh was well started on his work. Moreover, Williams was a student of James D. Dana, then at the height of his fame and the most eminent geologist of his generation. It was, however, a time of "species-making," and perhaps nothing shows better the fine quality of Williams' mind than the fact that, notwithstanding the precedent established by the eminent geologists of his impressionable years, he invented a new method of stratigraphic study.

When Professor Williams began his scientific work, it was held that a distinct set of fossils characterizes each geological formation, but he soon learned that there are exceptions to this important rule. In studying the Devonian formations about Ithaca, he found that the so-called characteristic fossils of the Hamilton formation, for example, also occur in certain beds in the Ithaca; that in the Ithaca Group there is, "first, a Portage fauna, then the Ithaca fauna; third, the Portage fauna again, and finally Chemung capped by the Catskill and Carboniferous." This discovery, fundamental as it is, was not immediately welcome to all paleontologists, because, as one said, "How is one to be sure of the age of any formation if one can not depend on the characteristic fossils?" This practical inconvenience at first prejudiced his colleagues against his observations, but the principal is now an accepted dictum of paleontology.

Williams' chief permanent contributions to the principles of paleontology were the result of a method of collecting which he appears to have originated and which requires great patience, care, and time.

In collecting fossils from a section a careful and full examination is made, if possible, of every foot of the section from bottom to top, and where any change in the faunal content is noticed a separate field number is given to this faunule. If when studied carefully in the laboratory it is found that some of the faunules of adjoining beds contain faunules so closely alike as to signify practically the same set of species, associated in the same biological equilibrium of relative abundance, they are grouped together. When collections made in this way from a number of sections near enough to each other are studied, some of the faunal zones can be identified in the different sections. It was by this method that his theory of the "shifting of faunas" and of "recurrent faunas" was demonstrated.

His statement of the changes in fossil faunas in passing geographically from place to place is as follows:

"Upon tracing single species across these sections, it was learned that the mutation of the species not only may be recognized on passing vertically upward through a continuous section, but that the more direct line of succession was often deflected laterally, so that the immediate successor of a particular fauna of one section was found not directly above it in the same section, but at a higher horizon in a section ten or twenty miles distant. This shifting of faunas was taken as actual evidence of migration."[2]

The correct correlation of the Catskill formation was an indirect result of the application of the principles growing out of his method. He demonstrated that instead of being younger than the Chemung the Catskill formation was contemporaneous with it, the Catskill fauna living in fresh or brackish water and the Chemung fauna in contemporaneous marine waters.

While examining the Devonian collections when on a visit to European museums, his thorough acquaintance with the faunas of the Cayuga Lake section enabled him to recognize the Tully limestone fauna (Devonian) as the equivalent of the fauna of the Cuboides zone of Europe. He thus established a definite line between the Eo and Meso-Devonian. He says:

"The conclusions we draw from this study of the faunas of the Cuboides zone and the Tully limestone are that within narrow limits, geologically speaking, the point in the European time scale, represented by the beginning of the deposition of the Cuboides Schichten of Aix La Chapelle, et cetera, is represented in the New York sections by the Tully limestone, and, second, that the representative of the fauna of the Cuboides zone of Europe is seen in New York not only in the Tully limestone, but in the shaly strata for several hundred feet above. Therefore, if we wish to express precise correlation in our classification of American rocks, the line between Middle and Upper Devonian formations should be drawn at the base of the Tully limestone to correspond with the usage of French, Belgian, German, and Russian geologists, who include Frasnein, Cuboides Schichten, and correlated zones in the Upper Devonian."[3]

A consideration of the theories of evolution delighted him, and he loved to speculate on the shades of meaning of terms used by Darwin, Huxley, and others. The best statements of his own conclusions are to be found in his Geological Biology (1895) and in papers that grew out of the writing of this book, which appeared in 1897 and 1898.

Professor Williams "was the author of upwards of 90 papers and books, comprising nearly 3,000 pages, and of these about 65 titles relate to

[2] The scope of paleontology and its value to geologists. Am. Geol., vol. x, 1892, pp. 148-169.

[3] Bull. Geol. Soc. Am., vol. 1, 1890, pp. 481-500.

stratigraphy. Incidental to his studies he described 16 new genera and more than 140 new species." [4]

He was the inventor of the now widely used method of photographing fossils after coating them with ammonium chloride deposited on the fossils by the union of hydrochloric acid fumes and those of ammonium.

Professor Williams was an investigator rather than a teacher. That he thoroughly understood the theory of teaching, however, is proved by a reading of a paper on the Methods of Instruction in General Geology. This paper,[5] as far as the writer is aware, contains the best suggestions for the presentation of this difficult subject that has yet appeared. He was, nevertheless, not notably successful as a teacher or a lecturer for undergraduate students.

A former student and his successor at Yale says:

"Williams was not a 'popular' teacher, as voted by the Senior class. He knew no tricks of the lecture platform and cared little for applause. He found it difficult to formulate dramatic situations and impossible to be dogmatic; his statements were accompanied by qualifications and exceptions. Williams loved the truth as few men love it; he was not content with half truths. The effect of this style of teaching was easily seen in the reaction of the class. At first the teaching seemed confusing; few clear-cut sentences could be written in a note-book, and cramming for tests on the basis of catch phrases was a very difficult task. Before the end of the course, however, the class realized that under the name of geology they were learning the greatest lesson open to men—the method of weighing evidence and thus arriving at the truth." [6]

With his graduate students he took as his model Louis Agassiz, and occasionally would illustrate Agassiz's method by the oft-told story of the fish skeleton which Agassiz gave a student for study. One who studied under him as a graduate student says:[7]

"He did not believe in directing each separate step which his pupils took, but he believed rather in leading them to search for their own problems, and when found to solve them independently, if possible. He considered the field of scientific paleontology to be limited in its possibilities for a livelihood, and consequently he never offered undue encouragement to prospective students to enter the work. To those who were bound to enter, however, he gave the best that he had in him in counsel and advice. He was especially a laboratory teacher and made his students feel that they were companions with him in research. . . . His own experience during his early days at Cornell led him to advise his student always to search for and solve the problems that were to be found in their own dooryard, rather than to think that any problem worth solution must be found in distant parts of the earth."

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[4] Charles Schuchert: Henry Shaler Williams; an appreciation of his work in stratigraphy. Am. Jour. Sci., vol. xlvi, 1918, pp. 682-687.

[5] American Naturalist, vol. xxi, 1887, pp. 616-626.

[6] H. E. Gregory: Memorial address, Cornell University.

[7] Stuart Weller: Journal of Geology.

Professor Williams was a charter member of and one of the founders of the Geological Society of America. "It appears probable," says Prof. Herman L. Fairchild, that "the initial gathering of the Society, with representatives from different places, was held at Ithaca on the suggestion and invitation of Professor Williams. He certainly had immediate charge of the arrangements and was thanked by name along with the trustees of the university, and in the evening he and Mrs. Williams received the fellows of the university at their residence." [8]

Professor Williams was also the founder of the Society of the Sigma Xi.

"The fine scientific spirit of Henry Shaler Williams shows itself nowhere more potently than in his connection with the Society of the Sigma Xi. Here he was truly a pioneer, a missionary, and a prophet. His sense of the nobility and majesty of science, of its deeper philosophical significance, and of its proper place in the higher education became manifest.

"What the society would have become but for his influence we know not; but that it would have been very different from the Sigma Xi today is certain. The little group at Cornell, who in 1885 and 1886 were planning for its establishment, were engineering students. They had in mind an honorary society for engineering students. He persuaded them to build upon a broader foundation; to include pure science without excluding its applications. Thus there came into existence, largely through his labors, which extended over many years, a Phi Beta Kappa for science, but with new ideals and broader functions.

"In his conception, Sigma Xi was to stand for three important things, not even yet fully realized after more than thirty years, but in process of realization: (1) The recognition of scholarship and science, even as scholarship had long been recognized in the humanities. (2) The establishment of a new criterion of fitness, more subtle and significant than the old standard of marks or class standings—that is, the promise of achievement in research. (3) The linking together of the great family of sciences through an organization of the workers in all departments of research, so that the sundering and estrangement due to modern specialization might be ameliorated and sympathy and cooperation fostered." [9]

Respected by those who knew him, blest with loyal friends, successful in the chosen profession which he loved, enabled almost to the day of his death to do a work which was a constant joy to him, Professor Williams leaves an indelible record of his achievements in a great science in which great men have worked and will work for generations to come.

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MEMORIAL OF SAMUEL WENDELL WILLISTON [1]

BY HENRY FAIRFIELD OSBORN

Samuel Wendell Williston, our distinguished senior colleague in vertebrate paleontology, passed away August 30, 1918, honored and beloved by all who knew him. Our admiration for his character and achievements is enhanced through a perusal of his personal recollections[2] of his career, which reveal long struggles toward scientific attainment, lofty ideals of exploration and research, and an unfaltering determination. In the opening pages of his reminiscences he writes:

"As the oldest living student of vertebrate fossils in America and one of the oldest in the world, friends have urged me to write some of my recollections. Not that I am so very old, but because there were so few vertebrate paleontologists in the days when I first became interested in the subject—only Leidy, Cope, Marsh, and a few other lesser lights in America. Nor were there more than a dozen others in all the world, of whom Sir Richard Owen was the chief, who had published much about extinct vertebrates. It has never seemed to me that there was much of interest that I could say about myself, nor very much about the pioneers in paleontology that I could tell. I begin to feel that there are not many more years of work before me, and to regret that I have not accomplished more. . . . But the way has often been hard, and I am thankful to be spared so long and to have done what I have."

And again, in closing:

"My life, as I look back on it, has had many discouragements and many pleasures. I have made many mistakes, as I now can see, and I have not accomplished what I might have done. If I may extenuate my views, I will say that for a country boy, with but little help and wholly without influence, the road to success is very hard. . . . Perhaps for me experience was the best teacher, and an easy path in youth might have caused failure. But it was hard, and I have more than once been discouraged. I have drifted along somehow, with one underlying ambition—to *learn*. My plans and ambitions may seem fickle, first as an engineer, next as a physician, as a chemist, entomologist, paleontologist. I have tried various things, when one of them, steadily pursued, would have been better. In reality there was only one ambition—*to do research work in science*. And I have realized that ambition in a measure. I have published about 300 books and papers, totaling about 4,000 pages. But the chief satisfaction that I find now in looking back over my life is that I have been the means, to some extent at least, of assisting not a few young men to success in medicine and in science."

Like all men of science who have risen to distinction, Williston was self-made, the impulses all coming from within; yet he was instinctively

[1] Abstract of article, Journal of Geology, November-December, 1918.

[2] See Recollections, an unpublished autobiography, written May, 1916; copyrighted by Mrs. S. W. Williston.

S. W. Williston

alert to seize every chance to learn and to expand his horizon. We can not imagine a life story more helpful than his to the youth predisposed to science who has both to discover his own talent and to explore every avenue of opportunity which presents itself.

Williston was born in Roxbury, now a part of Boston, July 10, 1852. "The Williston family," he writes, "has been traced back to about 1650 in Massachusetts; they were about the usual run of common people, no one famous or even noted, whether for good or evil. . . . Some of them served in the War of the Revolution and many were fishermen." His father was born in Maine, and he remarks of this branch of the family that "they knew little of schools. My father, if he ever went to school, did not take kindly to study, for he never learned to read or write. . . . It was a great pity, too, for my father was a man of far more than ordinary ability as a mechanic—he was noted always for his skill. . . . Of all his children I resembled him the most, both physically and mentally." His mother was from England, having come with her parents to New Jersey about 1812. She had a fair common-school education, and the effects of her early English training and her accent remained through life.

The intellectual and social environment of Roxbury probably never would have produced a geologist or a paleontologist, and while the next step in Williston's life was hard, yet it was propitious, as the events proved:

"In the spring of 1857 my parents decided to emigrate to Kansas. A colony had left the year before for Manhattan, and the letters that came back had infected many with the desire to go West. . . . The abolitionists were urging eastern people to colonize the territory in order to help John Brown preserve it to the 'Free States.' . . . The trip was long and tedious by rail to Saint Louis, then a small place, and thence by steamboat up the Missouri River to Leavenworth. There was no Kansas City then. We reached Leavenworth about the twentieth of May. Here we remained a few days in a very small hotel, while my father bought a yoke of oxen and a wagon and such provisions and household things as were indispensable, and we started on the slow and tedious drive of 115 miles to Manhattan through a country but very sparsely settled. For the most part we children rode in the covered wagon, while my father and cousin walked and drove the oxen."

In a small single room, with a loft, in a log cabin about fifteen feet square, the family was brought up. The four boys slept in the loft above. The Potawatomie Indians had a village in the immediate vicinity. The first building erected in the new town was the stone school-house, to which books were supplied by the Emigrant Aid Society. At the age of seven young Williston made his first collection of fossil shells from de-

posits since determined as belonging to the Lower Permian. Following school, he entered the State Agricultural College in 1866. At the age of fifteen he came under the rare influence of Prof. Benjamin F. Mudge, who loaned him a copy of Lyell's *Antiquity of Man.* Professor Mudge conducted all the courses in natural history, and through his splendid character and example exerted a great influence on young Williston. It was quite by accident, however, that seven years later Williston was included in Professor Mudge's party to northwestern Kansas (Smoky Hill Valley Cretaceous), where Professor Mudge, already famous through his discovery, in 1872, of a specimen of *Ichthyornis,* was collecting. He writes:

"We left on the fifth [July, 1874]. *It was this accidental and thoughtless decision that led to my life's devotion to paleontology.* Had I not gone with him, in all probability I would today have been a practitioner of medicine somewhere in Kansas. We joined Mudge about the fourteenth and started almost immediately south. In a few days I found a good specimen of pterodactyl and became an enthusiastic lover of the sport of collecting fossils—for sport it seemed to me. I had planned that autumn to go East, if I could borrow a couple of hundred dollars, to attend a medical college. And so I returned to Manhattan by rail in September, but did not succeed in getting the necessary funds. Mudge thereupon asked me to return, which I did about the first of October, and remained until we returned in November. . . . For my season's work Mudge paid me $25, which bought me a suit of clothes and other things badly needed. My total cash income this year was not more than $50. It was the hardest year of my life. My board I worked for in part, in part I had it paid for by my parents, but I did not have a second whole shirt, and when I gave my address I had to borrow clothes to wear, for my clothes were ragged and patched.

"Times now began to improve. Professor Marsh and Professor Cope, as is well known, were rivals and very jealous of each other. They had been quarreling with each other for two or three years, with mutual criminations and recriminations. Because of the discoveries Marsh was making in the Cretaceous of Kansas, Cope grew eager to participate in them, but could find no one to undertake these collections, for Marsh was afraid to have too many learn about the region for fear that Cope would seduce some of the assistants by the offer of higher pay. He therefore instructed Mudge to retain his assistants of the previous summer. Brous and I were engaged for the following season at $35 a month and our expenses. We accepted the offer gladly and started for the field overland in early March, meeting Mudge at Ellis, on the railroad. We stipulated that I should quit in September to allow medical lectures. . . .

"We collected chiefly along the Smoky Hill Valley that season, as far west as Fort Wallace, and got many valuable specimens. . . . By Marsh's directions, each had signed his name to the specimens he had collected. Perhaps that was the reason he invited me in February to come to New Haven. I promptly accepted his invitation and sold my watch and borrowed enough to take me there in March. . . . It was thus with feelings almost of awe that

I met Professor Marsh for the first time at New Haven, Connecticut, on March 19 or 20, 1876. My heart was in my mouth when I knocked at the basement door of the old Treasury Building and heard the not very pleasant invitation to 'come in.' There was a frown on Marsh's face, accentuated by his near-sightedness, as he waited for me to state my business. No doubt he thought me a wild and woolly westerner, in my military cloak, slouch hat, and cowboy boots, as I stammered my name. But he quickly made me feel more at ease. He found me quarters in a little building in the rear of Peabody Museum, then approaching completion. The next day he set me at work studying bird skeletons with Owen's *Comparative Anatomy* as a guide. He was then deeply interested in his Odontornithes and wanted newer specimens, especially of the smaller forms, which were very difficult to find in the Kansas chalk. For recreation I helped a few hours every day to carry trays of fossils to the museum."

Williston was now twenty-four years of age. Vertebrate paleontology had become his first love, but he had leanings toward human anatomy and medicine and entomology, first as an avocation and then as a vocation. He was afforded no independent opportunities for paleontological research and publication by Professor Marsh. In the summer seasons of 1876 and 1877 he collected with Professor Mudge in the Cretaceous chalk of Kansas. In 1877 he was sent by Professor Marsh to the Morrison, Canyon City, and Como quarries to cooperate with Professors Lakes and Mudge and Mr. Reed in taking out the types of *Atlantosaurus, Diplodocus,* and other sauropods. In Professor Marsh's laboratory Williston worked on the dinosaurs. In the field in 1878 he helped to collect the "Jurassic mammals" and some of the smaller dinosaurs. For nine years (1876-1885) he worked in Professor Marsh's laboratory, where he became closely associated with Marsh's other assistants, especially Harger and Baur, who influenced him greatly and for whom he had great admiration. He wrote a biographic note on Harger in 1887, which gives some interesting side lights on the relations of Professor Marsh to his assistants. In 1878 he published a brief communication on American Jurassic dinosaurs in the *Transactions* of the Kansas Academy of Sciences; but he had very little opportunity for further publication in vertebrate paleontology as long as he was in New Haven. This led to the renewal of his medical studies.

While acting as assistant in paleontology he studied medicine at Yale, received the degree of M. D. in 1880, continued his postgraduate studies, and received the degree of Ph. D. at Yale in 1885. He then became demonstrator of anatomy (1885-1886) and professor of anatomy (1886-1890) at Yale and practiced medicine in New Haven, where he was health officer in 1888-1890.

In 1886 he published some criticisms of Koken's work on *Ornitho-*

cheirus hilsensis, which give us some hint of his abiding interest in Kansas fossil reptiles, an interest which was soon to bring great results.

The turning point in his scientific career, from anatomy and medicine to paleontology, came at the age of thirty-eight, when he returned to the University of Kansas as Professor of Geology. Kansas was the scene of his first inspiration in paleontology, and here his fossil studies and vigorous health marked the happiest period of his life. He taught both vertebrate and invertebrate paleontology, anatomy, and medicine, and several of his students have achieved distinction in these fields.[3] With respect to the breadth of his studies and of his influence at this time, his life was comparable only to that of Joseph Leidy, who, it will be recalled, was at once an anatomist, a physician, a paleontologist, and a microscopist of distinction. He soon began to publish studies on the Cretaceous reptiles of Kansas. Henceforth Kansas plesiosaurs and turtles, mosasaurs and pterodactyls, were the subjects of a long list of papers, mostly in the *Kansas University Quarterly,* from 1890 to 1899, with occasional articles on Kansas fossil mammals (*Platygonus, Aceratherium, Teleoceras fossiger*). Meanwhile he made many explorations of the Cretaceous of Kansas for fossil reptiles.

At Kansas University Williston also kept up his two avocations of anatomy and dipterology; he served as professor of anatomy and dean of the medical school. He also continued to publish many papers on recent Diptera. He accomplished a great work on this group and became the leading dipterologist of the United States. His studies culminated in the preparation of his *Manual of North American Diptera*—a book which is indispensable to a beginner in dipterology and a very great convenience to advanced workers. His collection of Diptera from the United States and Canada is now in the University of Kansas; the remainder of his collection, including much of the valuable material which he had brought together while writing the volumes on Diptera in the *Biologia Centrali-Americana,* is in the American Museum of Natural History.

PALEONTOLOGIC WORK IN KANSAS [4]

Williston's paleontologic contributions on the Cretaceous fauna of Kansas began in 1879, with a short paper entitled "Are birds derived from dinosaurs?" and included fifty-three communications, chiefly to the

[3] Among these paleontologic students, who have since become known for their researches, were: E. C. Case, C. E. McClung, Roy L. Moodie, Herman Douthitt, Alban Stewart, Elmer S. Riggs, Barnum Brown, M. G. Mehl, E. B. Branson, and E. H. Sellards.

[4] These notes on Williston's work on fossil reptiles and amphibians have been prepared in collaboration with Prof. W. K. Gregory of the American Museum of Natural History.

Kansas Academy of Science, the *Kansas University Quarterly,* and the University Geological Survey of Kansas; also three volumes on the *Cretaceous Fishes,* in cooperation with Alban Stewart; and *Paleontology* (*Upper Cretaceous*), Part I, Volume IV, of the University Geological Survey, which was chiefly prepared by Williston, with the assistance of his students—Adams, Case, and McClung—and is a thorough review of the geology and marine fauna of the Cretaceous seas, containing the first clear distinctions and restorations of the great Kansas mosasaurs—*Clidastes, Platecarpus,* and *Tylosaurus.* This work became the standard for all subsequent researches of Osborn, Wieland, and others on the Cretaceous fauna. It contains some admirable restorations of mosasaurs and other fossils which may be compared with those of Dollo from the Maestrichtian of Belgium. The second part, Volume VI, of the University Geological Survey, covering the Carboniferous and Cretaceous, published in 1900, included the Cretaceous fishes, alluded to above, and the Carboniferous invertebrates, by Joshua W. Beede.

In 1897 Williston published his first paper on Paleozoic tetrapods—a brief description of "A new Labyrinthodont from the Kansas Carboniferous"; his second was on the "Coraco-Scapula of Eryops Cope," in 1899; but nearly a decade elapsed before the Paleozoic reptiles and amphibians became his chief subject. From 1897 to 1902 he was engaged chiefly on his series of papers on fossil vertebrates of Kansas for the University Geological Survey of Kansas.

Williston concluded his studies of the Cretaceous fauna during the early years of his professorship in Chicago, beginning in 1902. Thus his work on the Kansas Cretaceous fauna, following the very disjointed contributions of Leidy, Marsh, and Cope, based on inferior material, marks the turning point in this field to the new order of description and generalization based on complete material, including even the skin impressions of several great mosasaurs. In his observations on the mosasaurs, plesiosaurs, pterodactyls and marine turtles, and the birds with teeth, Odontornithes, he placed the osteology of these several animals on a much more secure basis, adding a number of new generic types, such as a short-necked plesiosaur, *Dolichorhynchops osborni.*

His interpretation of function and habit is shown in his restorations of all these types, and his first observations on the feeding habits of the plesiosaurs and his more mature views on several of these animals were published during his sojourn in the University of Chicago, namely, "Relationships and habits of the mosasaurs," *Journal of Geology,* 1904; "North American Plesiosaurs," 1903, 1906, 1907. His first contribution to the phylogeny and classification of the Reptilia as a whole appeared in

1905 and was followed by his important discussion of this subject entitled "The phylogeny and classification of reptiles," *Journal of Geology*, August, 1917. In this article, which expresses his mature opinions, he departed from his previous conservative attitude toward classification and proposed to add two subclasses of reptiles, the Anapsida and Parapsida, to the subclasses previously proposed by Osborn, namely, the Synapsida and the Diapsida, making a fourfold grand division of the Reptilia. Doubtless it was Williston's intention to fortify this system of classification in his forthcoming general work on the Reptilia.

WORK ON PRIMITIVE AMPHIBIANS AND REPTILES [5]

In 1902, at the age of fifty, Williston was called to the University of Chicago as head of the new department of vertebrate paleontology—a chair which he occupied with great distinction and with continued influence for the remaining sixteen years of his life. He now began to concentrate his attention more exclusively on vertebrate paleontology. During the first six years he continued his studies and publications on the Cretaceous reptiles; then he began to turn toward the study of far more difficult and obscure problems, namely, the relatively primitive amphibians and reptilian life of the Permian, where in several groups he marked the beginnings of the higher forms which he had previously studied, as well as the adaptive radiation of the lower forms to a great variety of habits and habitats.

Prof. E. C. Case, now of the University of Michigan, who was one of Williston's students at the University of Kansas, had cooperated with the late Prof. Georg Baur at the University of Chicago in the study of *Dimetrodon* and other Permian reptiles and had collected for that university a number of important types of pelycosaurs and cotylosaurs. After Baur's untimely death, Case continued to collect and study the Permian reptiles and amphibians of Texas and other States, finally issuing his well known Carnegie Institution monographic revisions of the Pelycosauria and Cotylosauria, in which he revised and extended Cope's work on these animals and figured the types and other important specimens in the American Museum of Natural History, in the University of Chicago, and elsewhere. Thus Cope, Baur, Case, and Broili had opened and partly explored an important field of work which Williston had long desired to enter.

Accordingly, in 1907 and 1908, Williston began to publish on this subject, which occupied most of the closing decade of his life and constituted perhaps his greatest contribution to science. It is pleasant to record that

[5] See footnote, p. 70.

Williston and Case at all times fully and cordially cooperated with each other in the study of Permian reptiles and amphibians. In 1908 he published an important but brief paper on the Cotylosauria, containing a description of the skeleton of *Labidosaurus incisivus.* In the same year Mr. Paul C. Miller, of the American Museum of Natural History, a collector and preparator of high rank, became Professor Williston's assistant at Chicago, and under his direction began a long series of explorations in the Texas Permian, which have yielded results of the greatest importance to vertebrate morphology and paleontology. During the next decade these expeditions brought back to the university a great number of specimens, some of which will become more and more famous as their great importance is gradually realized. More or less complete skeletons were discovered, extricated with great skill, and admirably described in a long series of publications. Among the more important of the new or little known skeletons were the following, which, to students of the early evolution of the skeleton of vertebrates, will ever stand as important types:

Pariotichus laticeps Williston
Trematops milleri Williston
Arœoscelis gracilis Williston
Seymouria baylorensis Broili
Casea broilii Williston
Mycterosaurus longiceps Williston
Trimerorhachis insignis Cope
Varanosaurus brevirostris Williston
Ophiacodon mirus Marsh

These were only the more conspicuous of the many priceless specimens which Williston and Miller have brought to light, and which the former has described and figured with the most painstaking care and accuracy. This material also enabled Williston to give definite and in many cases final figures of the sutural limits of the elements of the skull in most of these genera. Many investigators had attempted to do this from less extensive and complete material, but their results were often uncertain in detail and subject to important changes and corrections.

In 1911 he published from the University of Chicago press his volume, *American Permian Vertebrates,* which comprises a series of monographic studies on some of the genera already noted. This work contains many new and original plates. Careful and extensive definitions are given of the orders Temnospondyla, Cotylosauria, Theromorpha, and of the included families and genera. In the same year, by invitation of Professor Schuchert, Williston examined and described the important collection of Permian reptiles which Mr. Baldwin had collected for Professor Marsh

between 1877 and 1880, but which had never been thoroughly studied. Among other important results of this research was the erection of a new family of cotylosaurs, the Limnoscelidæ, to include the skeleton of *Limnoscelis paludis* Williston. In 1912 he published, in collaboration with Professor Case, a paper on the "Permo-Carboniferous of northern New Mexico," in the *Journal of Geology;* he also published a general review of primitive reptiles in the *Journal of Morphology.* In 1913 appeared a memoir, in collaboration with Case and Mehl, on *Permo-Carboniferous Vertebrates from New Mexico.* The same year saw the publication of his important papers on the primitive structure of the mandible in amphibians and reptiles and on the skulls of *Aræoscelis* and *Casea.* The close resemblance of *Aræoscelis* to the Squamata, especially in the temporal region, was noted.

Early in 1914 came the publication on *Broiliellus,* one of Cope's "batrachian armadillos," and the fuller description of the osteology of *Aræoscelis,* with a discussion of the relationships of *Aræoscelis,* the Protorosauria, and the Squamata. He then referred *Aræoscelis* to the Protorosauria and placed this order next to the Squamata. In the same year he published a series of life restorations of some American Permo-Carboniferous reptiles and amphibians.

His principal publication in 1914 was the book on *Water Reptiles of the Past and Present,* in which his life-work on these animals was admirably combined with the results obtained by other workers. Williston had shown a bent for the harmonious study of form and function, of structure and habit, of environment and adaptation, which he applied with skill and originality to the interpretation of the highly diversified forms of aquatic life. He followed Eberhard Fraas, of Stuttgart, in making a special study of aquatic adaptations in the vertebrates; consequently his book on the water reptiles constitutes one of the most important contributions which we have on this subject.

The year 1915 produced his papers on *Mycterosaurus,* a very interesting reptile, that threw light on the origin of the diapsid types, namely, of reptiles with *two* arches at the side of the temporal region of the skull; also on *Trimerorhachis,* perhaps the most archaic of the American temnospondyls, or amphibia, with the vertebræ composed of several pieces. In 1916 he published the careful description of the skull and skeleton of *Pantylus* and of *Theropleura,* together with the important discussion of the origin of the mammalian and reptilian types of sternum. This paper was followed by the admirable *Synopsis of the American Permo-Carboniferous Tetrapoda,* in which the principal types were illustrated and careful definitions of the various groups were given. In 1917 he began a

general work on the *Reptiles of the World, Recent and Fossil,* on which he was actively engaged up to his last illness; also the publication of his papers on *Edaphosaurus,* on the atlas-axis complex of reptiles, and, equally important, his brief paper on the "Phylogeny and classification of reptiles," previously mentioned. During the last two years of his life he was also preparing a paper on new Permian reptiles.

In summing up his life-work, "I like," says Doctor Gregory,[6] "to emphasize the general features in which Williston was really preeminent, namely: (1) Discovery of new material—Cretaceous Reptilia, Permian Tetrapoda, and Diptera; (2) conscientious and precise description of these; (3) eminently conservative synthesis of facts, so as to work out a great and enduring record of Cretaceous and Permian reptiles; (4) intensive and successful specialization in several distinct lines of research and teaching."

It is a matter of the deepest regret to all of Williston's colleagues in paleontology that he did not live to complete his great comparative work on the Reptilia, which would have summed up all his researches and observations and the facts store d in his mind which have never found their way into print. As an investigator he combined in an exceptional degree anatomic accuracy in detail with breadth of vision and power of analysis. His associates in the special field of Permian research considered his opinion as a homologist weighty. A committee was formed, chiefly composed of Americans, of which Williston was senior, to endeavor to establish the difficult and intricate questions of homology and to base on this an enduring terminology to replace the confusing whirlpool of names for certain skull bones which have accumulated since the time of Cuvier.

A few of the more general features of Williston's life-work and character are as follows: He strove arduously through forty years of investigation to discover new material in the field and to widen our basis of facts in several distinct lines of investigation; he preferred to discover new facts rather than to reinterpret older ones or to adjust the interrelations of facts; in general, his material was notably of his own finding. Nevertheless, especially in his late years, he labored very successfully to classify and synthetize his material, and with it that which had been treated by other workers. Here his genial personal character and admirable relations with his colleagues shone forth; he was singularly appreciative of the work of other men and ready to adopt whatever he believed to be solid and enduring in previous attempts at classification. Thus Williston's work stands in contrast with that of Cope and Marsh, whose personal differences of opinion led to the setting up of two entirely

[6] See footnote, p. 70.

distinct systems of classification as well as of nomenclature, irrespective both of priority and of merit.

Williston's keen, broad knowledge of human anatomy, of the muscles as well as of the bones, doubtless aided his penetrating insight into the habits of the extinct animals, and while generally conservative and cautious his phylogenetic studies and suggestions were of high value. His views on taxonomic standards[7] and on college and high-school education[8] were, like his views on paleontologic problems, characteristically sober, moderate, and well considered, lighted up in their expression with his genial, half-humorous manner. He was ready to confess and appraise defects or faults on his own side, but quick to resent exaggerated accusations and criticisms from the other side.

His friends and colleagues met him last at the Pittsburgh meeting of the Paleontological Society of America, December 30, 1917, and enjoyed a few of his short and characteristically enthusiastic communications and discussions. With Doctor Holland, myself, and many other warm friends, he stayed the Old Year out and saw the New Year in at the Society smoker. He returned home quite suddenly, and this was the last occasion on which we were privileged to enjoy his genial presence, his humorous narratives, and his inspiring influence in paleontology.

REPORT OF COMMITTEE ON PUBLICATION OF MAP OF BRAZIL

The Committee on the Publication of the Branner Geological Map of Brazil reported progress, the black and white base plate being completed and the color plates being well along in preparation. Work on the map has been unavoidably delayed by conditions arising from the war and by other circumstances.

The Photograph Committee, subsequent to the meeting, has reported as follows:

REPORT OF COMMITTEE ON PHOTOGRAPHS

The collection of photographs belonging to the Society has remained stored in my office, Room 2209, New Interior Department Building, Washington, where it is convenient of access to persons wishing to examine the prints. There have been no calls for it during the past year and no accessions.

N. H. DARTON, *Committee.*

There being no new business to transact, the Society then proceeded to take up the program of scientific papers.

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[7] "What is a species?" Am. Nat., vol. xlii, pp. 184-194.

[8] "Has the American college failed to fulfil its function?" Proc. Nat. Educ. Ass'n. 1909, p. 526.

TITLES AND ABSTRACTS OF PAPERS PRESENTED AT THE MORNING SESSION AND DISCUSSIONS THEREON

GEOLOGY AS A BASIS OF CITIZENSHIP

BY JOSEPH E. POGUE

(*Abstract*)

Changing economic circumstances in the United States are placing a growing emphasis on the efficient utilization of mineral resources. An effective outcome in this direction will depend on a wide-spread public appreciation of the basic facts of mineral resource limitatons and capabilities. As these basic facts are drawn from the science of geology, the ultimate responsibility is here. Coordinated effort on the part of the geologists of the country, expressed through the Federal Geological Survey, the State surveys, universities, museums, and other educational agencies, and through numerous contributions to popular literature, will go far toward giving to the average citizen a more effective basis of citizenship.

Read by title in the absence of the author.

SOURCES AND TENDENCIES IN AMERICAN GEOLOGY

BY JOSEPH BARRELL

(*Abstract*)

In the revaluation of general ideas going forward at the present time, ranging from politics to science, a question which concerns us is that relating to the trend of geologic research. This involves a review of the past in order to gain our bearings for the future.

The foundations of geology were laid in Great Britain and France. At the present time America is a leading contributor to both geologic fact and theory. The myth of German supremacy in science, which was industriously cultivated up to the opening of the world war, was never true in geology, except for a time in the divisions of mineralogy and petrology. In the future Germany will probably play a subordinate rôle in the development of geology in general.

A knowledge of German has generally been required of all candidates for the degree of Doctor of Philosophy. The question should be discussed at the present time if it would not be wiser to permit the candidate in geology to choose two languages from French, German, and Spanish, permitting him, if he wishes, to avoid the learning of German and encouraging him to learn the language of a neighboring continent, where geologists should take their part in the development of natural resources.

Read by the author from manuscript.

GEOLOGY AS A SYNTHETIC SCIENCE

BY WARREN D. SMITH

(*Abstract*)

The scientific work of the past three hundred years has consisted of discovery and analysis. The time is now ripe for synthesis of the natural sciences. Geology, though almost the youngest of these, is the logical clearing-house of

such studies. The present war has shown the profound influence of the various branches of geology on the conduct as well as the causes of wars. Innumerable and very striking examples of the material relationship of this science to our modern civilization are well known. The greatest contribution, however, is to philosophy, through the paleontologists on the one hand and through the cosmogonists on the other, resulting in a rational and optimistic conception of life.

Read by title in the absence of the author.

UNITED STATES GEOLOGICAL SURVEY AS A CIVIC INSTITUTION DURING THE WAR

BY SIDNEY PAIGE

(*Abstract*)

The Geological Survey has for many years specialized in certain sorts of knowledge. The occurrence, origin, and distribution of raw materials have been systematically studied. Water as a power resource has been made the subject of intensive study in the field and in the office. Topographic surveying had progressed as an art and as an engineering profession to a degree unexcelled in the world. Map-printing has attained a similar high standard.

The Survey, with this store of practical information, was in a position to have a viewpoint broad enough to be useful under the new conditions brought about by the war. The Government, for example, undertook to regulate the expenditure of new capital. The Survey was called on to decide, in cases where prospective mining operations were involved, whether the national interest justified such expenditure. Many cases could be decided from the data at hand. Others demanded field investigations, and such were made.

The distribution and reserves of war minerals, their occurrence abroad, their relations in trade, the stimulation of domestic production, all became matters of investigation and report on short notice to the war boards vitally concerned. One of the first calls on the trained personnel of the Survey was from the newly created Fuel Administration. From the basis of a personnel supplying yearly statistics of coal output, an organization was built up which successively supplied quarterly, monthly, and weekly statistics of the output of coal, and toward the end of the war of the daily movement of coal.

In the division of Water Resources problems connected with the development and distribution of power were taken up, and efforts were made to correlate new industries with existing power supplies, to connect plants in order to improve load factors, and properly to distribute fuel.

Statistics of world production of minerals have been gathered and the mineral reserves of the world estimated. This work has proved of value to the Shipping Board in the allocation of shipping and to the General Staff in studying the effects of the shifting battle line. A knowledge of the distribution of mineral resources and the extent of reserves is fundamental as a basis for a sane peace.

A noteworthy contribution to the effective prosecution of the war was the coordination of the activities of the large number of governmental agencies dealing with minerals and mineral derivatives. As a result of the Survey's

initiative, there was created a Joint Information Board on Minerals and Mineral Derivatives, on which were represented more than thirty boards and bureaus.

Problems of the domestic petroleum supply for war purposes received particular attention. Careful estimates of the country's oil resources were made by oil and gas geologists. At the same time exploration by drill was carefully followed and every effort made to extend assistance. The search for undiscovered pools was pushed vigorously. Thus, with the cooperation of the Administration of Indian Affairs, it was possible, in Oklahoma, by examinations and publication before leasing, to cause drilling to be concentrated in places where conditions were most favorable for large production.

In short, the Survey has supplied necessary information; it has carried on investigations of various sorts to obtain specially needed information; it has given technical advice to the Government in the capacity of consulting geologist, and it has supplied personnel to other organizations.

Read by the author from manuscript.

MILITARY CONTRIBUTION OF CIVILIAN ENGINEERS

BY GEORGE OTIS SMITH

(*Abstract*)

The original distinction between military and civil engineers has gradually lost its force. Growth in civil engineering has resulted, and thus have arisen a variety of engineers in the civil service of the Government.

Cooperation of the United States Geological Survey with the Army in military mapping. Memorandum suggesting a reserve corps of engineers. Legislation of 1916. Utilization of civilian organizations in engineering work and commissioning of engineer officers for military service overseas.

Presented in abstract by the author from notes.

PRESENTATION OF GEOLOGIC INFORMATION FOR ENGINEERING PURPOSES

BY THOMAS WAYLAND VAUGHAN [1]

(*Abstract*)

The author first made a summary statement regarding requests for certain kinds of information on cantonments addressed by Army and Navy officials to the United States Geological Survey. These requests were classified under four topics, as follows: (1) Selection of sites, (2) nature of foundations, (3) material for highway construction, (4) water supply.

The services a geologist may render in the selection of sites was illustrated by three instances. In the account of the selection of one site, that for the artillery range and cantonment, named Camp Bragg, near Fayetteville, North Carolina, particular emphasis was laid on the value of knowledge of the general features of the country, because by such knowledge efforts will not be wasted on searches within areas in which there are only unsuitable tracts, but will be restricted to areas in which conditions are favorable for the project in mind. Mention was made of information furnished on the foundation for a radio

[1] Published by permission of the Director of the United States Geological Survey.

tower and on the nature of the basement for a dam intended to serve as a flood control for a water-supply reservoir. It was said that data on road-building material were eagerly sought for some of the cantonments, and two special examinations revealed the presence of material suitable for highway construction right at the places where it was needed. Inquiries regarding sources, quality, and quantity of water supplies covered all aspects of such supplies, except sanitary analyses; and reports based on at least 17 special field examinations were made to Army or Navy officials.

With regards to military mapping, the author stated that the Chief of Engineers of the Army had requested and had utilized practically all available information on water supply and material for highway construction that was in proper form for incorporation in the progressive military map of the United States, now in preparation by the Engineer Corps of the Army. Mention was made of the expression of high appreciation by the Army officers for aid in procuring information of this kind.

The author then said that as the demands made on the geologists in connection with the war seem to render clear the need of bearing more definitely in mind the application of geology to practical things than has been customary in the past, he had, with the assistance and advice of many friends among geologists, engineers, and Army officers, prepared a paper entitled "Instructions for members of the United States Geological Survey engaged in geologic mapping for military purposes," which has been issued by the Director of the United States Geological Survey, and that in connection with the instructions certain forms for field and others for office use had been designed. A part of the intent of these instructions is that such information as may be desired for use on part of the military map of the United States will be collected and will be so presented that it may be easily taken over and incorporated in the military map. Copies of some of the forms were exhibited. Three subjects are particularly emphasized in the instructions and the forms for presenting data. They are as follows: (1) Water supplies, which are to be treated under the captions (*a*) wells, (*b*) springs, (*c*) artificially impounded waters, (*d*) public water supplies, (*e*) stream waters, including natural lakes and ponds, and the water table. (2) Structural and road material. (3) Geologic map and table of geologic formations with reference to transportation and to engineering operations.

In closing his paper, the author said that every kind of information covered by these instructions has been called for by military authorities, and that he believes such information should be available in case of unexpected emergency. Furthermore, he said, that as, except for the form in which some of it is cast, very nearly all, if not all, of this information is of use in peace-time economic development, it is his conviction that work on areal and structural geology should be prosecuted with all possible energy, and that the application of geologic information to the ordinary practical things of life should be more clearly recognized and given more prominence than has hitherto been the custom.

Read by the author from manuscript.

Discussed by Messrs. Bailey Willis and the President.

ENGINEERING GEOLOGY IN AND AFTER THE WAR

BY CHARLES P. BERKEY

(*Abstract*)

The nature and extent and importance of the service of geology in the late military operations, and the state of preparedness of responsible men and organizations for putting this science to its fullest use, will be made the text for comment and suggestion bearing on the present period of academic reconstruction.

Presented in abstract by the author from notes.

Discussed by Messrs. Whitman Cross, O. E. Meinzer, H. M. Ami, A. W. Grabau, and G. F. Loughlin.

Discussion

O. E. Meinzer: I wish to indorse the statements of the last speaker to the effect that what the geologists have gained by their war work is not in contributions to principles or methods of the science, but in the training they have received in applying their results to intensely practical problems and in the inspiration that has come from finding that these results were of definite value in the great national crisis. The United States Geological Survey has long acted, in an informal way, as consulting geologists for the War and Navy Departments in matters of water supply. When the war came this relation was continued; but the demands for advice became much more numerous, until by the end of the war practically all the water-supply geologists that had not entered the Army were working on War or Navy projects. The War and Navy Departments did not want long erudite reports, but very definite and concisely stated advice on which they could act immediately. A number of the reports were made in telegrams—some of them brief telegrams. There was immense inspiration in the realization that our scientific work could be put to such definite use in the prosecution of the war.

I wish also to call attention to the work done by the Ground Water Division of the Survey for the War Department in locating practically all watering places and localities where water supplies could be developed in the region within 100 or 150 miles of the Mexican border, for 350 miles, from Tucson west. Almost complete data are now available to the War Department on water supplies along the border from El Paso to the Pacific coast.

GEOLOGY IN THE STUDENTS' ARMY TRAINING CORPS

BY HERBERT E. GREGORY

(*Abstract*)

The purpose of the Students' Army Training Corps was to provide physical and mental training for prospective officers. Obviously, the equipment of officers should include a knowledge of soils, ground water, rivers, swamps, and topographic features as seen in the field and as read from topographic maps. At the request of a committee of the War Department, the Division of Geology

and Geography of the National Research Council outlined courses and prepared texts and syllabi on the understanding that geology should take a prominent place in the program of studies of the Students' Army Training Corps. As finally issued, the program included a required course in surveying and map-making—a course such as is commonly given to students in railroad engineering and which involved no knowledge of geology and little practice in the use of topographic maps. Geology, including physiography, was listed with 24 other subjects which were open to election. The result was that about 5 per cent of the prospective officers received instruction in geology.

This unsatisfactory showing led to a study of the status of geology in educational institutions. It was found that the number of high-school students studying geology has been rapidly decreasing and now is about 0.5 per cent; that of 512 colleges and universities large enough to qualify for Students' Army Training Corps units, 43 per cent offer no geology. In the 294 institutions which provide for undergraduate teaching in geology, the department faculty consists of one man who gives all or part of his time to this subject in 58 institutions, and in 173 colleges and universities geology is taught by instructors in other subjects. The statistics show that since 1900 the number of students electing geology has suffered a large relative decrease and probably an actual decrease.

There is much food for thought in the status of geology as revealed by experience with the Students' Army Training Corps and by a study of university faculties and curricula.

Is geology taking its proper place in educational systems? Is it making a satisfactory contribution to national progress and welfare? And if not, why not? Is it true that a knowledge of geology is fundamental in efficient exploitation of the soil and in the development of mineral resources? If so, why are geologists rare in agricultural schools, experiment stations, and on the staffs of mining and quarry companies? Has geology significant contributions to make to engineering problems and to military operations? Then why are most of the dams, tunnels, and foundations and wells constructed without the aid of geologists, and why has it required such skillful maneuvering to assign geologists to the Army staffs in France? Has geology a message for high-school pupils and college students? Is it true that this subject is particularly valuable in developing the imagination, in weighing evidence, in gaining an intelligent notion of time? Is it fitted to increase the happiness of people by enlarging their enjoyment of natural scenery? Belief in the educational value of geology is common among geologists, but many college presidents and faculties view the idea with skepticism. Shall we consider a knowledge of geology as a special attainment within the range of a small group, and shall geologists continue to write books for each other to read and criticize, or shall we consider that the facts and methods and principles of geology should form part of the mental equipment of intelligent citizens and write books which can be understood by the average man? These are some of the questions which require study if progress in our science is to be stimulated; for advanced study flourishes best in a sympathetic environment, and the training of students and a wide public knowledge of the value of geology are primary conditioning factors in research.

Read by the author from manuscript.

WAR WORK BY THE DEPARTMENT OF GEOLOGY AT THE UNIVERSITY OF OREGON

BY WARREN D. SMITH

(*Abstract*)

At Oregon we have a general situation probably without a parallel in other State universities of the country, namely, a State university without a school of engineering. Fortunately for the department of geology, one of its members had had some experience in geographical and military map-making and reading, and a class of sixty-five volunteer students in this subject was enrolled before war was declared by the United States. Since the declaration of war by America more than one thousand men have received this training.

The second activity was in the line of geography. A year's course in economic geography had been given for three years previously to our entrance into the war, and the central theme of this had been the geography of Europe. Geography had a few years before been dropped from the university curriculum.

The third and perhaps the most interesting phase of the work was the prospectors' class in war minerals, held in the evening hours once a week during the spring of 1918. As the United States swung more and more earnestly into the war the department began to give the young men (such as came under its instruction) planning to go to officers' training schools more and more applications of geology to military operations. And yet another field was entered to a limited extent, which might have been more fruitful had time and energy permitted, namely, the extension field. Several outside lectures, including one at Fort Stevens, at the mouth of the Columbia, on the geography of the western theater, were undertaken.

Read by title in the absence of the author.

At 12.30 o'clock p. m. the session adjourned for noon recess and luncheon, and reconvened at 2.10 o'clock p. m. to continue the reading of papers.

Afternoon Session, Friday, December 27, 1918

TITLES AND ABSTRACTS OF PAPERS PRESENTED BEFORE THE AFTERNOON SESSION AND DISCUSSIONS THEREON

RECENT EARTHQUAKES OF PORTO RICO

BY HARRY FIELDING REID AND STEPHEN TABER

(*Abstract*)

A series of earthquakes lasting about a month were felt in Porto Rico and adjoining islands, beginning at 10.14 a. m. October 11, 1918. The origin of the shocks was submarine, a few miles off the northwest corner of Porto Rico. The first shock occurred without warning and was very severe, causing great destruction of buildings in the northwestern part of the island, and some minor damage, even as far as its eastern end. This was followed by many

aftershocks, which were very numerous for a few days, but gradually became less and less frequent. Shocks strong, but not nearly so strong as the first one, occurred at 11.43 p. m. October 24 and at 5.44 p. m. November 12. After that date they rapidly diminished in strength and frequency and soon ceased.

The first shock was felt from the northern Lesser Antilles to the western part of the island of Haiti—a distance of 300 to 350 miles. The first shock, but none of the others, was followed by a sea-wave, which reached a height of about 20 feet in the northwestern part of Porto Rico, and, its height in general diminishing with the distance, was noticed for some distance along the northern coast, over the whole of the western coast, and for a short distance on the southern coast. A number of people were drowned by this wave and many small native huts were destroyed or displaced.

The earthquakes are believed to be due to movements on a submarine fault. The slope of the sea-bottom off the northwestern part of the island is so steep that one is almost driven to assume that a great fault-scarp exists there. The movement at the time of the first shock must have had a vertical component to generate the strong sea-wave.

Although both the Greater and Lesser Antilles are subject to strong earthquakes, the island of Porto Rico seems to have experienced only one other severe disturbance since it was discovered by Columbus; this disturbance was also submarine to the east of Porto Rico and immediately south of the island of Saint Thomas. The shock inaugurating this disturbance occurred on November 12, 1867. It was rather more severe than the recent shock, and was also followed by a more important and more extensive sea-wave.

(A full report will be made to the Insular Government, and technical details will be published in the Bulletin of the Seismological Society of America.)

Presented by the senior author extemporaneously.

Discussed by Prof. C. P. Berkey.

STRUCTURE OF THE PACIFIC RANGES, CALIFORNIA

BY BAILEY WILLIS

(Abstract)

The term Pacific ranges of California is here used to designate the Coast ranges and the Sierra Nevada. Their structure is described as an effect of compressive stress, but is contrasted with the structure of the Appalachians, whereas in the latter the effects of compression are folds and low angle overthrusts; in the Pacific ranges the dominant structure is the rotated mountain block guided by a high angle upthrust.

Ben Lomond Ridge, in the Santa Cruz quadrangle, the Santa Inez Range, west of Santa Barbara, and the Sierra Nevada are cited as examples of rotated mountain blocks. In each case their visible surfaces are two—an old topographic surface, which has been tilted, and a fault-scarp, which has been more or less eroded. Rotation of the block is regarded as demonstrated by the growth of consequent streams and canyons on the old topographic surface, and also by normal faults, similar to landslides, in the direction in which tilting would cause downslipping.

Rotation has resulted in the uplift of one edge of the block—the edge in

which the old topographic surface is intersected by the fault-scarp. The upward movement may be described as a high angle upthrust. The plane of the thrust rises to vertical or even beyond vertical and appears, especially when eroded, as a normal fault-plane, hading to the downthrow. In fact, however, it is by hypothesis neither normal nor plane. It is regarded as a curved thrust surface, curving back under the block.

Since the under side of the block can not be observed, its form is hypothetical; but if the rotated block moved on it as on a guiding surface, it must be a curved surface, as described above. The only alternative would be that the mountain block floats. This is dismissed as inadmissible. Hence the curved under surface of the block is regarded as proved by the rotation.

The under surface of the block is extensive. Its visible margin is the fault-scarp. It extends downward probably many miles and seaward many tens of miles. It is a major structure which requires explanation.

Independent studies into the possible effects of isostatic adjustment had led the writer to conclude that erosion and sedimentation are quantitatively too weak to produce mass movements in the rigid earth, but that they do set up stresses adequate to direct the orientation of crystals in the development of schists. The orientation should vary from a horizontal attitude of foliation beneath loaded areas to a vertical attitude beneath lightened areas, and should constitute a curve rising from a great depth beneath the ocean basins to the continental border zones. Shear stresses at approximately 45 to the horizontal should supplement the effects of orientation by isostatic stress. Long time is a very important factor. The result should be a discoidal structure of the lithosphere. It is believed that this structure is a general condition to a depth of a hundred miles or more. The hypothesis has been tested as a clue to understanding various phenomena of orogeny, vulcanism, and mineral zones. In connection with the rotated mountain blocks of California, it is held that their under surfaces are elements of the discoidal structure of the lithosphere.

The force which moves the rotated mountain blocks and causes them to rise on their guiding under surfaces is found in the weight of the failing sub-oceanic mass, as when water pushes out a dam. In discussions of isostatic balance it is commonly assumed that the opposed horizontal pressures of two adjacent failing columns are transmitted through homogeneous or structureless material. To produce motion their difference would then needs be greater than the crushing strength of the material. But when an inclined foliation has developed, the components of pressure against an inclined plane come into play and cohesion is largely replaced by friction as a resistance to upthrust along that plane. Even so, it is the fact that stability of the lithosphere is the prevailing condition. Imperceptible warping has been more common than energetic mountain growth. To explain the latter, hypothesis appeals to the occasional greater activity of recrystallization and of melting in deep-seated schists, due to variations of internal heat. The two processes may or may not be associated. Recrystallization may produce gradual movements. Melting and the intrusion of molten sheets along planes of schistosity may so reduce friction as to occasion revolutionary orogenic disturbances. Some evidence of association of igneous rocks with orogeny can be adduced, but in general the relation remains hypothetical because the zone of activity is beyond observation.

Whatever the validity of the speculative suggestions may be, it is believed that the recognition of the rotated, upthrust mountain block in place of the currently accepted normal fault-block will advance our understanding of the Pacific ranges.

In the paper due recognition is given to the work of Gilbert, Le Conte, Diller, Lindgren, Becker, and others in this field, and also to Barrell's studies of the conditions existing in the lithosphere.

Presented by the author without notes.

Discussion

Dr. R. T. Chamberlin: I have been very much interested in this new explanation advanced by Doctor Willis for the structure of these perplexing Pacific ranges. Some experimental studies which I have been carrying on have developed somewhat similar structures, and for their bearing on this problem may perhaps be mentioned. In these studies blocks of various materials were subjected to various compressive stresses from two opposite sides to determine the nature of fracturing. When rotational strains were developed, it was observed, in not a few cases, that the planes of fracture turned sharply upward as they neared the upper surface of the blocks. In these cases the fault-plane, which was nearly horizontal in the middle of a block, curved and reached the upper surface as a nearly vertical plane, thus manifesting a rather striking resemblance to the diagram presented by Doctor Willis. These results were noted in blocks of pure paraffine and other homogeneous materials, as well as in bedded strata, indicating that this behavior of the fault-plane may take place independently of the nature or special structure of the material if the strain is of the proper sort. Because of the similarity of these experimental fractures, though on a very small scale, to the curving fracture planes just presented, I venture to mention them as having a possible bearing on the problem.

Mr. A. Keith: I have observed for years in the Appalachians certain facts that accord with Professor Willis's analysis of the Pacific Coast structure. The rocks in the Appalachians that are known to have been most deeply buried have in very many cases a nearly flat foliation. Another major fact in the Appalachians is the association of many great flat overthrusts with flatly foliated gneiss or granite. It has long seemed to me that there is a close association in cause between the great flat thrusts and the flat foliation due to deep burial.

Dr. G. R. Mansfield: Curved fault-planes are recognized in the Rocky Mountain region along the Idaho-Wyoming border. The Bannock overthrust, with gentle southwesterly dip, shows in places a pronounced upturning. In several places dip even becomes southeasterly.

Dr. G. W. Stose: I have been trying to understand the mechanics of the diagram and how its operation will produce the results at the surface ascribed to it. It seems to me that movement of a block on an arc of a circle of one hundred miles radius would not tilt the surface of the block as stated.

Remarks were also made by Professors H. F. Reid and J. P. Iddings, with reply by the author to questions raised by Professor Reid.

MIGRATION OF GEOSYNCLINES

BY AMADEUS W. GRABAU

(Abstract)

The author, as opposed to Haug and others, distinguishes between geosynclines, or belts of concurrent deposition and subsidence parallel to the old land, and fore-deeps, or suboceanic areas of subsidence with a minimum of deposition. A consideration of a number of such geosynclines of various geological ages, and in various parts of the world, brings out the fact that on the folding of the strata of the geosyncline, and their elevation into a mountain chain, a new geosyncline came into existence, parallel to the earlier one, but within the region of the former old land, which supplied the material for the sediments of the preceding geosyncline. Thus the geosyncline migrates toward the old land. European examples are: The Molasse Channel, formed with the first folding of the Alps; the new geosyncline along the outer border of the newly formed Carpathians; and the similar late Tertiary geosyncline north of the Caucasus. In North America the deposits of the Newark geosyncline rest, in part at least, on the surface of the old land of late Paleozoic time, which includes some of the older Paleozoic strata; but the evidence in this case is not so clear as in others, probably because of the absence of the older Triassic. In western North America, however, we find a progressive westward migration of the geosynclines in Tria-Jurassic, Comancho-Cretacic, and Tertiary times, so that each series rests, in part at least, on the old land of the preceding geosyncline, though gradual overlap on the folded series, as this becomes peneplaned, may also occur. It is, of course, recognized that in front (east) of the folded Paleozoics of the Cordilleran region (in the present Rocky Mountain region) deposition continued throughout Mesozoic and later time, just as later Tertiary deposits continued to form south of the Alps, inside of the Carpathian arch (Hungarian or Pannonian Basin), and south of the Caucasus. In all of these regions there is essential concordance of strata, though disconformities exist, except where later overlaps bring the younger strata to rest on the eroded parts of the folded series.

So far as the available data permit judgment, a similar migration of geosynclinal belts occurred on the first elevation of the Atlas Mountains of North Africa and the Andes of South America, and it appears that this is a principle of wide applicability.

Presented by the author extemporaneously.
Discussed by Prof. Bailey Willis.

GEOTECTONIC ADAPTATION THROUGH RETARDATION OF THE EARTH'S ROTATION

BY CHARLES R. KEYES

(Abstract)

From the results of recent curious experiments in geotectonics, it is inferred that the larger relief features of our globe are not the complex dynamical phenomena commonly fancied, but that all are merely somewhat different ex-

pressions of the same simple tangential force and direct resultants of the earth's rotation.

Inquiry into the immediate origin of the great earth-wrinkles is usually approached from the astronomical angle. Since, on the assumption of a cooling globe, the contractional hypothesis takes form, it is commonly premised that the earth passes through much the same course as does a shriveling apple. Beginning with Descartes, three hundred years ago, and ending today with Suess, the contractional theory finds many adherents. Challenges are few and far between, but important, for they seem to show that the hypothesis has to be critically examined anew, in the light of the more modern advancements of the earth sciences.

As is well known, in a rotating spheroid possessing notable elasticity the geometric radius is not coincident with the radial line of molar equilibrium, or repose from stress. The first is a straight line; the second a section of a parabolic curve, the coefficient of which varies with the rate of revolution. For obvious reasons, the spheroid of the laboratory acts as a homogeneous body. Extending these physical principles to the earth, complications at once set in. The zones of rock-flow and of rock-fracture necessarily behave differently. The former acts as a homogeneous mass under hydrostatic pressure. The latter develops the characteristics of a heterogeneous body: it flexes, faults, and shears, and gives rise to all of those tectonic phenomena which are commonly accounted for on the hypothesis of a contracting nucleus. Tangential compression thus may be initiated without regard to a cooling globe.

Working with curved prisms, like sectors of the earth, with bands corresponding to gravitational control, and under conditions under which there is gradual release of rotational stress analogous to retardation of the earth's revolution, experiments lately performed reproduce to a nicety all of those larger structural features of the earth, such as the ocean basins, the continental arches, Cordilleran corrugations, and orographic foldings. The effects of tangential compressive force which many mountain structures display thus appear to be not the result of earth contraction, but of stress release due to retardation of the earth's rotation.

Finally, on this new basis, with the force and rate of retardation and the amount of crustal shortening capable of exact expression by mathematical equation, a ready means is provided for realizing not only something of Eliè de Beaumont's fantastic dream of orographic symmetry, but for gauging in units of human time the age of every mountain uplift, for determining very accurately in like terms the periodicity of every diastrophic movement, and for evaluating in years the span of every era, period, epoch, and stage of the stratigraphic records since life appeared on our globe.

* Read by title in the absence of the author.

LATE MISSISSIPPIAN OROGENIC MOVEMENTS IN NORTH AMERICA

BY FRANCIS M. VAN TUYL AND RAYMOND C. MOORE

(Abstract)

Recent stratigraphic studies have disclosed that the Ouachita disturbance of late Mississippian time affected a much larger area in North America than was

formerly supposed. In the northeastern portion of the continent there was an important uplift in the Acadian region. Farther south Appalachia was raised. In the southern interior there were important positive movements in the Llano area of Texas, in the region of the Wichita and Arbuckl Mountains of Oklahoma, and in New Mexico. The Ozark Mountains were elevated at this time, and there is evidence that the Nemaha Mountains, a granite ridge of north-central Kansas now buried by the Pennsylvanian, were formed during the same orogenic epoch. To the north there appears to have been an uplift of the Siouxian area in northwestern Iowa and adjacent parts of South Dakota and Minnesota, of Wisconsin, and of the La Salle anticline of Illinois. Brooks describes late Mississippian diastrophic movements in Alaska, and it is believed that there were similar readjustments in western North America at the same time. As a result of the orogenic movements enumerated above, several important structural basins were formed. At the beginning of the Pennsylvanian sedimentation in central North America, important geosynclines were present in Michigan, Illinois, Indiana, Kentucky, and Missouri, Iowa, Nebraska, Kansas, Arkansas, Oklahoma, into which advanced the Pennsylvanian seas and in which the Pennsylvanian deposits were laid down.

Read by title in the absence of the authors.

POST-GLACIAL UPLIFT OF THE NEW ENGLAND COASTAL REGION

BY HERMAN L. FAIRCHILD

(*Abstract*)

During the summer of 1918 examination has been made of eastern Connecticut, Rhode Island, Marthas Vineyard, Nantucket, eastern Massachusetts, and Cape Cod and points on the Maine coast as far as Mount Desert. The study confirms the practical accuracy of the map showing continental uplift, published in the Bulletin of this Society, volume 29, page 202 (and similar maps in *Science*, volume 47, page 616, June 21, 1918, and in Proceedings of the National Academy of Sciences, volume 4, page 230, August, 1918). Any changes in the lines of equal uplift (isobases) over southeastern New England will be slight and unimportant.

The evidence of submergence since the last ice-sheet is positive. Excepting marine fossils (which are not expected in deposits near the glacier margin and at higher levels), all classes of features are found that would be sought in proof of standing water. These are: delta plains at the summit level on all streams from higher ground; wave-planation of gravel areas (kames) at various levels; extensive still-water deposits at all lower levels; and prevailing pell-mell structure of water deposits at inferior levels, because they had been poured by glacial drainage into deep water. Clean horizontal lines, the common inscription of standing water, are very generally visible.

The sand plains in eastern Massachusetts, which have been attributed to glacial lakes, are only the effects of wave-work by the shallowing sea-waters. No glacial waters existed there except the higher levels of Crosby's Lake Nashua, for the reason that the areas of supposed lakes are all beneath the summit marine plane.

Deposits of standing water origin are found at or near the summit plane

at various localities facing the open sea, thus ruling out the idea of glacial waters.

The paper will give precise location and description of the marine features over the area in question.

Read by title by request of the author.

TOPOGRAPHIC FEATURES OF THE HUDSON VALLEY AND THE QUESTION OF POST-GLACIAL MARINE WATERS IN THE HUDSON-CHAMPLAIN VALLEY

BY JAMES H. STOLLER

(*Abstract*)

The subsidence of the body of waters (Lake Albany) which occupied the middle Hudson Valley following the retreat of the ice-front antedated the opening of the Saint Lawrence outlet of the interior glacial lakes. The evidence of this is the occurrence of erosion terraces in the Lake Albany deposits on either side of the Hudson River at Mechanicsville. The location, elevation, and trend of margins of these terraces show that they resulted from erosion by a western tributary river discharging into southward-flowing Hudson waters at Mechanicsville. It has been shown that this tributary was the Iroquois-Mohawk River. Other topographical evidence shows that the waters of the Hudson Valley, after their subsidence to the levels indicated by the erosion terraces, did not again rise to a higher level. The deductions from these facts of topography are opposed to the conception of a body of marine waters connecting the Saint Lawrence arm of the sea with the ocean at New York.

Presented extemporaneously by the author.

Discussion

Prof. H. L. Fairchild: The map which I now exhibit (published as plate 10 in volume 27 of the Bulletin of this Society) shows the full amount of the marine submergence of the Hudson-Champlain Valley. The upraised marine plane now rises from zero south of New York City to at least 740 feet on the international boundary, at Covey Hill. (The details of the shore features in this valley are awaiting publication as a bulletin of the New York State Museum.)

The rise of the land following the removal of the ice-sheet was by a wave movement, and at the time of the latest flow of the Iromohawk River, in the Saratoga-Round Lake region, the locality had risen 175 feet; but it was yet 200 feet lower than it is now. It is quite possible that the Hudson Valley in the region of New York City had then received its full amount of uplift, but the Covey Hill district was then at its maximum depression. Even after the extinction of Lake Iroquois the Covey Hill district was 740 feet lower than at present.

The erosion features in the Mechanicsville district, described by Professor Stoller, were made by stream-flow—first, by the Iromohawk, down to the 200-foot plane; second, by the southward flow of all the Laurentian waters while the glacier front rested against the highland of Maine and New Brunswick; and, third, by the present Hudson and Anthony Kill. These features of stream-

work are independent of and with no relation to the higher levels of the Hudson estuary.

The evidence of the continuous high-level shore phenomena throughout the Hudson-Champlain, the Saint Lawrence, Connecticut, and all other deep valleys of northeastern America (see Bulletin of the Geological Society of America, volume 29, pages 187-234), is proof of postglacial marine submergence. The stream-erosion features at Mechanicsville are carvings in the estuary deposits, produced while the region was rising out of the standing waters. That the so-called "Lake Albany" waters were estuarine and not glacial has been shown in the Bulletin, volume 28, pages 291-292.

Professor Stoller said: I defer to Professor Fairchild's extended study of glacial history in its broader aspects. Without entering on a controversy as to any of the larger questions, I would ask Professor Fairchild to state how he accounts for the topographic features I have called attention to in my paper.

May I ask Professor Fairchild whether he is able to understand the terrace forms at Mechanicsville which I have described as erosion terraces as due to currents flowing in the Hudson Valley waters?

SUBTERRANEAN "CHALK-STREAMS" OF NORTHERN FRANCE

BY EDWARD MOORE BURWASH

(*Abstract*)

1. British base in France corresponds largely with portion of French coast underlain by chalk—their lines of communication and battle-front during the war mainly on this formation.

2. Minor streams of this area, and many tributaries of the major ones, flow subterraneously through the chalk, under dry valleys.

3. Peculiarities of these valleys: (1) flat bottoms; (2) graben in the level flows; (3) fault-scarps on slopes parallel to the valley.

4. Relation of these facts to one another:

(1) Pattern of valleys erosional, not structural.

(2) Course of streams under valleys irregular—traceable by graben

(3) Fault-scarps sometimes on one slope of the valley, but absent on the opposite side.

(4) Streams sometimes under the side slopes of the valley.

5. Explanation. Meandering of underground streams—removing layers of chalk and allowing slumping of blocks above.

6. Suggested history of such streams.

7. Their importance as source of pure water.

Read by title in the absence of the author.

RELATIVE EFFICIENCY OF NORMATIVE AND MODAL CLASSIFICATIONS OF IGNEOUS ROCKS

BY EDWARD B. MATHEWS

(*Abstract*)

Among the chief outstanding differences in classifications of igneous rocks are the bases underlying them, and among these perhaps the widest divergence

is shown in the use of the norm as distinguished from the mode, or actual rock. The use of the norm increases the definiteness of chemical classification, but loses touch with the actual rock. The present paper is an attempt to test the relative refinement of chemical characterization of correlative groups in the old and new methods of classification to see whether or not the gains compensate for the losses.

The problem proposed is the testing of the relative homogeneity of the types as determined by specific diverse systems of classification. The method employed has been an arithmetical consideration of the eight constituents commonly present in rocks as represented in the superior analyses collected by Washington. The grouping of these analyses was based on that proposed by Iddings for the normative and by the names applied by different authors for the modal classification.

A preliminary study included the empirical examination of the effect of the choice of few or many examples, taken at random, on the range of values of the several constituents. This shows that in most instances 50 examples give only approximate results and that more than 150 examples add little to the observed ranges. The quantities of the several constituents were tested for the range in actual amount and the ratio between oxides and groups of oxides in the analogous groups developed by the normative and modal classifications respectively.

The method applied failed to show that the introduction of the norm, with subsequent groupings as applied by Iddings, gives an improvement in chemical characterization to commensurate groups sufficient to compensate for the loss in other characterizing factors. For chemical units smaller than those generally recognized in the classification of rocks, the normative method is capable of progressive logical refinement impossible in the modal classification, involving minerals of isomorphic series. When these smaller units are grouped together the chemical characterization is more definitive verbally, but not actually, and probably inferior to results obtainable by a quantative modal classification.

As a method of dividing chemical complexes (rocks) into groups in which some inter-relationships of constituents are fairly constant and others practically disregarded, the normative method is eminently successful. That this success in the grouping of *rocks* implies not only that the particular chemical relationships selected are more fundamental than others, but that they are also more fundamental as characteristic of igneous rocks and more valuable than the sum of all of the modal characteristics combined, since the normative classification disregards modal characteristics for the sake of bringing out with refinement the few chemical characteristics. Even so, the actual chemical characterization is not appreciably closer.

Presented in abstract by the author from the manuscript.

Discussed by Prof. J. P. Iddings and Dr. Whitman Cross, with reply by the author.

PEGMATITE, SILEXITE, AND APLITE DIKES OF NORTHERN NEW YORK

BY WILLIAM J. MILLER

(*Abstract*)

Acidic dikes of various types are abundantly developed in many portions of the Adirondack syenite-granite series. More recently it has become evident to the writer that certain generally accepted interpretations are not satisfactory when applied to these acidic dikes. It is proposed to use the term "silexite" for all masses of pure, or nearly pure, silica genetically related to pegmatite or aplite and usually of dike origin.

Pegmatite, silexite, and aplite dikes are wonderfully displayed in almost countless numbers in the granites of the Lyon Mountain quadrangle. Some of the more important conclusions resulting from their study are as follows: (1) by far most of the pegmatites consist simply of quartz and potash feldspar, with minerals indicating the former presence of mineralizers other than water vapor almost entirely absent; (2) pegmatite and silexite dikes are very abundant in a fine to medium to fine-grained facies of the granite and relatively rare in a coarse-grained facies, while the aplite dikes appear to be practically confined to the coarse granite; (3) both pegmatite and silexite masses began to develop while the granite magma still possessed a very considerable degree of fluidity, and they continued to form until the enclosing granite almost, or possibly completely, solidified; and (4) the aplite dikes were formed during a late stage of consolidation of the enclosing granite, but none as early as the earliest pegmatite and silexite masses and probably none as late as the latest pegmatites.

Acidic to rather basic dikes are commonly associated with many of the small gabbro stocks of distinctly later age than the syenite-granite series in the Adirondacks. Detailed studies within the North Creek quadrangle have led to the following conclusions: (1) acidic masses ranging from pegmatites rich in quartz and potash feldspar and with or without tourmaline, to pegmatite which is mostly potash feldspar, to basic pegmatite consisting chiefly of plagioclase with more or less hornblende, to aplite dikes, and to even nearly pure quartz (silexite), developed as satellites of the stocks of normal medium-grained gabbro; and (2) development of the pegmatites began while the gabbro was still notably fluid and continued until it had almost or completely solidified.

Presented in abstract by the author from notes.

Discussed by Mr. Arthur Keith, Prof. J. P. Iddings, and Dr. Whitman Cross.

MAGNETIC IRON-ORE DEPOSITS OF CLINTON COUNTY, NEW YORK

BY WILLIAM J. MILLER

(*Abstract*)

First, the magnetic deposits, including those of the Lyon Mountain mines, will be considered from the standpoint of mineral resources for war needs and post-war reconstruction. Emphasis will be placed on the extent of the ore

bodies, their excellence for the production of high-grade Bessemer iron, and their accessibility.

Second, the mode of occurrence and origin of the ores will be discussed. In all of the fifteen or twenty mining localities studied by the writer, the ores, in the form of irregular masses, lenses, or bands, usually with indefinite boundaries, were observed to be in close association with a fine to medium grained granite, older hornblende gneiss or gabbro, and pegmatite. Evidence will be presented to support the view that the ores are not straight magmatic segregation deposits, but that they are direct results of the process of pegmatization, the ores probably having been largely or wholly derived from the old iron-rich hornblende gneiss or gabbro.

Presented in abstract by the author from notes.

Discussed by Dr. Whitman Cross.

Adjournment for the day was taken about 4.45 p. m.

Session of Friday Evening, December 27

The evening session consisted of a round-table discussion, held in connection with the annual subscription smoker, at the Southern Hotel. About one hundred and twenty-five members of the Geological Society of America, Paleontological Society, and Association of American Geographers met, under the chairmanship of Prof. Bailey Willis, and listened to the following paper:

COOPERATION IN ADVANCED GEOLOGIC INSTRUCTION

BY HERBERT E. GREGORY

(*Abstract*)

This paper suggests three ways in which advanced instruction and facilities for research in geology might be improved: 1. Organize at a few institutions stronger departments of geology than now exist at any institution. 2. Arrange courses and select faculties in a group of neighboring institutions having strong departments of geology, to the end that, for example, one university should develop stratigraphy, another economic geology, and arrange for free interchange of students. 3. Encourage the departments of geology in educational institutions, the United States Geological Survey and State surveys to combine in financing and managing one or more efficiently organized field schools, attendance at which should be required of all students who plan to become professional geologists. It is recommended that such a cooperative field school be organized as soon as practicable in order to overcome a recognized weakness in present geologic training.

Professor Gregory's paper was followed, on call of the chairman, by remarks by Professors Charles P. Berkey, George F. Kay, J. C. Merriam, and William M. Davis.

Session of Saturday Morning, December 28

The Society was called to order, about 9.30 o'clock, by President Cross, who called for the presentation of the report of the Auditing Committee.

REPORT OF AUDITING COMMITTEE

The Auditing Committee reports that it has checked the accounts of the Treasurer and found the cash balance as stated in the printed report. Items of disbursements have been compared with the vouchers therefor. Interest on investments has been paid in full. The securities listed will be later examined by one of the committee and his report thereon forwarded to the Secretary.[1]

(Signed) Henry B. Kümmel.
W. C. Mendenhall.
Edward W. Berry.

The printed report of the Council was then taken from the table and, on motion, duly made and seconded, was approved. After sundry announcements by the Secretary, the reading of scientific papers was taken up.

TITLES AND ABSTRACTS OF PAPERS PRESENTED AT THE EVENING SESSION AND DISCUSSIONS THEREON

HIGH-GRADE CLAYS OF THE UNITED STATES

BY H. RIES

(*Abstract*)

The United States requires a large amount of high-grade clay for use in ceramic and other industries. Much of this was formerly imported from Europe, but the foreign sources of supply having been partly shut off by the war, it has become necessary to draw on domestic supplies as far as possible.

It has been found that domestic clays can replace imported ones to a larger extent than hitherto practiced, and there are probably abundant reserves in the United States.

White residual clays are developed from: 1, pegmatite veins, in North Carolina; 2, Cambrian schists, in southeastern Pennsylvania; 3, Cambrian quartzites, in central Pennsylvania; 4, Cambrian shales, in Virginia; 5, Cambrian limestones, in Missouri, and, 6, Oriskany shales and limestones, in Pennsylvania. These supply the china, paper, and paint industries.

[1] Since the meeting the Secretary has received, under date of January 6, 1919, the following communication:

"On behalf of the Auditing Committee of the Geological Society of America, I examined on January 4, 1919, the securities of the Society in the safe-deposit box at the Baltimore Trust Company and found them to be as listed in the printed report of the Treasurer (proper coupons attached).

"(Signed) Edward W. Berry."

In Georgia and South Carolina there are abundant deposits of white sedimentary clays of Cretaceous age of value to the pottery, paper, and paint industries.

In Florida the white sedimentary Tertiary clays, so valuable in the whiteware industry, contain abundant reserves.

The States of Mississippi, Tennessee, Kentucky, and Illinois are supplying large quantities of refractory band clays from the Wilcox formation, which are specially interesting because they can replace much of the clay for graphite crucibles and glass pots, formerly obtained from Germany.

Presented in abstract from notes.

OCCURRENCE AND ORIGIN OF WHITE CLAYS AT SAYLORSBURG, MONROE COUNTY, PENNSYLVANIA [1]

BY FREDERICK B. PECK

(Abstract)

The clay occurs below an arch in the coarse Oriskany sandstone, which arch runs northeast-southwest along the north side of Chestnut and Cherry ridges, in Monroe County, Pennsylvania. The anticline pitches to the southwest. To the northeast the sandstone roof has been removed. To the southwest it is more or less intact.

The clay has resulted from local alteration of calcareous shales (Stormville series) and clayey limestones (Bossardsville limestone) beneath the Oriskany arch. Before removal the arch, with impervious beds above, acted as a receiver under which the CO_2 gas, resulting from the decomposition of the limestone, accumulated under pressure, hastening and thoroughly completing the decomposition of the shales and limestones. Prospects to the southwest, where the roof of the arch is more or less intact, encounter CO_2 gas. In one case it escaped so rapidly and in such quantities as to drive the workmen from the opening. The sound of the escaping gas was distinctly audible and resembled the escape of air from the valve of an automobile tire. Numerous fossils of Helderberg age are found in the clays.

All of the important occurrences of the white clay are along the course of an ancient drainage system, remnants of which are seen in the Wind Gap, south of Saylorsburg, and in the low points in Chestnut and Cherry ridges at Saylorsburg and east of Mount Eaton.

Presented by title in the absence of the author.

OIL GEOLOGY IN RELATION TO VALUATION

BY RALPH ARNOLD

(Abstract)

A summary of results obtained and conclusions reached in the course of investigations undertaken for the United States Department of the Treasury.

Presented by title in the absence of the author.

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[1] Presented with permission of the State Geologist.

ROCK PRODUCTS AND THE WAR

BY G. F. LOUGHLIN

(*Abstract*)

As the subject "war minerals" has been generally used to designate war-scarce minerals, attention has naturally been focussed on these, and it is doubtful if many realize how indispensable a part such common things as stone, lime, clay, sand, and gravel have played in winning the war.

Limestone was by far the most important of these, 95,000,000 short tons of it being used in 1917. Of this quantity more than 25,000,000 long tons were used for furnace flux, 26,000,000 short tons for crushed stone, 23,000,000 short tons for Portland cement, and 7,500,000 short tons, either raw or burned, for chemical use in a great number of industries, most of which were essential in time of war. Besides meeting the greatly increased demand for chemical use, limestone and dolomite supplied special demands formerly supplied by imported materials. Most important of these was the substitution of dead-burned dolomite for Austrian magnesite.

Quartzite, whose principal product was ganister or silica brick for refractory use, increased in output 50 per cent in 1916 and 51 per cent in 1917. Sandstone was also used for lining Bessemer converters, and consolidated sand and gravel took the place of special grades of European sand and flint grinding pebbles.

Of the igneous rocks vesicular basalt replaced a German basalt formerly used in paper-making machinery, and granite gave promise of being successfully used in proposed nitric-acid towers, plans for whose erection were canceled soon after the signing of the armistice. Mica schist for refractory use increased output from 40,000 tons in 1917 to 150,000 tons in 1918.

In short, our rock products have been sufficient to meet the war requirements, and bring us to realize more strongly than ever that abundance and diversity of these accessory, as well as the primary, mineral resources is essential to our industrial independence.

Presented in full extemporaneously.

MANGANESE ORE AS A WAR MINERAL

BY D. F. HEWETT

(*Abstract*)

Although it was widely realized early in 1917 that only proper use of available ships would permit maximum military effort by the Allies, plans to conserve ships by restricting imports of minerals, such as manganese, pyrite, and chrome, were only put into effect after eleven months of war. Studies of these industries were submitted by several governmental bureaus to the organizations directing war activities, between June and September, 1917, but final action to restrict imports was taken in March, 1918, by the Committee on Mineral Imports and Exports of the Shipping Board, formed in January, 1918. Restrictions were accomplished by using the licensing power of the War Trade Board, at first conferred in June, 1917, to control trading with the enemy.

As domestic manganese deposits had supplied but a small part of the needed ore since 1892, it was difficult to convince those charged with maintaining supplies for the industries that the known domestic deposits were capable of supplying a considerable part of the needed ore. This, together with the slightly inferior quality of most of the domestic product, greatly hindered the maximum rate of production until the summer of 1918. During 1918 domestic mines supplied about one-third the needed high-grade manganese ore.

Presented in full extemporaneously.

ECONOMIC LIMITS TO DOMESTIC INDEPENDENCE IN MINERALS

BY GEORGE OTIS SMITH

(*Abstract*)

The war demands placed on the United States created many new problems in connection with the supply of raw materials. To meet the war demand for every mineral raw material was the larger task set before the mineral industry, and the degree of success attained and its cost are the basal facts in any inquiry as to the economic limits that must be recognized in developing the domestic supply. Both economic law and business sense were being applied to new problems and in new ways in obtaining the raw materials for a nation's expanded industry. Under these special conditions of supply and demand some minerals have taken on new values—indeed, certainty of supply has had larger significance than price.

The war program, with its reaction on industry, has opened the eyes of many to old facts. Mineral raw materials have won a recognition based on the new realization of their value. De Launay's recent and apt characterization of coal and iron as the two "grand seigneurs" of the mineral world is in strong contrast with the ancient idea of nobility among metals. The new measure of value is usefulness.

Economic geology is useful geology—the theoretical science applied to meet the material needs of man. These human needs as presented in the last four years have demanded a specialized type of geology—the application of geology in terms of commerce. Geology to be most useful in these days of world problems must take the world view of values, and we find ourselves working in commercial geology—that is, geology applied in terms of commerce. The world is the field of commerce, and the requirements of commercial geology are simply that the geologic relations of a Nevada ore deposit, for example, must be observed with an eye trained to see far beyond the basin range; the geologist needs to compare the quality and quantity of the unmined ore here with similar facts of nature that give value to the ores in other districts, as in Peru or Burma.

Geology must needs continue to furnish the basal facts, but the geologist has a call to go further than he has gone heretofore in the interpretation of his facts—not simply by translating his technical words into the language of the market-place, but, more than that, by showing the relation of geology to national life.

The practical question concerns not simply the quantity of metal present in the ore, but the quantity that can be won to the profit of mankind. First of

all, then, in fixing the economic limits to the utilization of domestic mineral deposits, comes the balancing of cost of production with the value of the product.

The proper valuation of national independence in raw materials therefore requires a careful weighing of the emergency factor, which introduces the insurance idea, as well as an estimating of future possibilities of lower costs as the industry develops. The incidental or the ultimate advantage may be so large as not to be seen by those who take too close a view of cost accounting or are short-sighted in their outlook on the nation's business. The old contradiction of penny-wise and pound-foolish holds true today in matters of cents and dollars.

A composite diagram of either current output or future reserves of the essential minerals for the countries of the world would show so large a centralization in North America as to suggest that here is a group of nature-favored nations. This strategic advantage expresses itself in the well recognized large degree of self-sufficiency of the United States, so that the question of economic limits to domestic independence concerns a relatively small number of minerals and makes our problem quite different from that in other and less favored nations. However, whether the debatable list includes only chromite, manganese, pyrite, and potash or is much longer, clear analysis of the economic problem is needed, for cost-keeping on a national scale is the only safeguard against a loss which is real, even though not at once apparent.

It is true that the measure of economic worth must be the welfare of the individual, the community, and the people of the nation, and not the dollar of profit to the corporation or the State, yet only a successful industry can be made to serve both owner and workman and the public as well. If the product is not actually worth its whole cost, no camouflage of bounty or tax exemption or import duty will long conceal the inherent weakness of the industry. The basic importance of the raw material resources to the country makes it a prime public duty of citizens generally to know the facts regarding the mineral industry, and to ascertain these facts the intensive study of our own resources is not enough; we must also acquire a comprehension of what minerals other countries contain to supplement what we have at home.

Read in abstract from manuscript.

DISCUSSION

Dr. G. F. LOUGHLIN: Following Doctor Berkey's remarks, it appears that more team-work in geology is required. There are geologists and geologists. Some are particularly adapted to certain lines of research; others more inclined to industrial application of geologic results; others perhaps who have not concentrated in specialties may be well adapted to administrative or some other line of work. While these different men may have cooperated more or less in the past, they need to keep in closer touch with each other now, and also to keep in closer touch with technologists and commercial organizations if geology in its many branches is to be of the greatest service to the public.

Dr. F. E. WRIGHT: There is a tendency at the present time to emphasize the utilitarian aspects of science; research is measured by its "usefulness." This attitude is justified, provided the quality of usefulness is gauged correctly.

There is a short-range usefulness which satisfies an urgent present demand and is successful to the extent that it meets the need as seen. There is, on the other hand, a long-range usefulness which fills no present need and which might be counted useless, but which in time may prove to be of far greater value than the short-range variety; thus the work of Faraday and Maxwell on electricity laid the foundation for modern electrical development, including wireless telegraphy and telephony, and yet Maxwell's work is highly mathematical and abstract in the extreme. Practical men and the public in general have little sympathy and appreciation for "*pure research*," as they term it, and yet the greatest and most unexpected economic advances have resulted from abstract research rather than from studies of direct practical bearing.

Great industrial corporations are learning to view research properly and employ in their laboratories, in addition to technical experts and routine factory men, scientists on abstract research, from which no immediate application or commercial return is expected. The task before industrial and governmental organizations is to strike the proper balance between short-range and long-range research, such that the commercial or popular demand is met and yet a continuous stream of results from investigations into fundamental principles is maintained, from which ultimately far-reaching practical applications will flow. It requires a mind of vision to establish this balance; the narrow-minded man considers only the immediate yield of tangible results. The workman is paid according to the quantity and quality of his daily labor. The man of research, on the other hand, may not obtain the results he is seeking for months or even years; but he is necessarily a man of adaptability and resource, and if placed in executive positions will function better than the man of limited vision. In large organizations the man of research is liable to be engulfed by executive tasks which pay better and are better appreciated by the business world. Abstract research is not generally recognized as public service of the highest kind and is commonly poorly paid; it takes patriotism and enthusiasm of a high order for an efficient investigator to remain at research.

The record which scientists have made during the present war in solving industrial problems has been excellent, and many manufacturers appreciate now the advantages of scientific control within the factory. They are offering scientists factory and executive positions and scientists are naturally answering the call. This situation has many favorable features, but steps should be taken to counteract the tendency to absorb the best research men in this manner; otherwise much research will be lost which might be of the greatest value and this country will lag behind others and be placed at a disadvantage. The conservation of research men for research is a critical task at the present time.

Remarks were also made by Messrs. Whitman Cross, J. P. Iddings, J. Barrell, C. P. Berkey, and D. White, with reply by the author.

IMPERIAL MINERAL RESOURCES BUREAU, LONDON, ENGLAND

BY WILLET G. MILLER

Presented by title in the absence of the author.

SOME PROBLEMS OF INTERNATIONAL READJUSTMENT OF MINERAL SUPPLIES AS INDICATED IN RECENT FOREIGN LITERATURE

BY ELEANORA F. BLISS [1]

(*Abstract*)

One important reason for the recent war was the commercial and industrial supremacy of Germany. In "Germany's Commercial Grip on the World" Hauser shows the conditions that were potent factors in causing the war: First, the sudden rise in German industry, which has necessitated the organization of a drastic cartel system to combat the dangers of unlimited competition entailed by overproduction; second, the further relief of this overproduction by means of foreign "dumping," and, third, the temptation to stabilize a somewhat shaky financial foundation by the accession of foreign capital.

The "Future of German Industrial Exports," by Herzog, sets forth the means by which Germany proposes after the war to regain her former commercial position. Certain German industries that are indispensable to some foreign countries are to be placed under State protection in such a way that it may be possible without killing the industry to place an absolute embargo on its market in any foreign country which has shown injurious discrimination against Germany. In post-war commercial treaties Herzog demands, in addition to an open door for German trade, all kinds of special provisions operating to the benefit of German trade in order that it may be safeguarded in every possible way.

Comparison of the production of the United States, Great Britain, France, and Germany in the five most important minerals, namely, coal, iron, copper, lead, and zinc, shows that the United States leads in all five, while Germany and Great Britain divide the control of production among the three European nations. The United States, by means of her large imports, holds the dominant industrial control of raw materials, but among European nations Germany, by means of her imports, has acquired the foremost place in all except the lead industry.

France was handicapped by her deficiency in mineral resources. By the restoration of Alsace-Lorraine she will obtain 75 per cent of Germany's output of iron ore, but will still be deficient in coke to treat these ores. De Launay, in "France Allemagne," calls attention to the fact that France can not obtain that coal from Great Britain on account of the cost of transportation and that it must be drawn from Germany. Iron and steel must be exported to Germany because France has not the necessary coal to work them up into finished products, even if she should acquire the Saare coal district. Special provision must, therefore, be made to admit French iron and steel into Germany duty free.

MacFarlane, in "The Economic Basis of an Enduring Peace," suggests the expropriation of the Westphalian coal fields, but acknowledges that by the loss of her iron ore and coal Germany would be completely wrecked as an industrial power and that undue industrial supremacy would accrue to France. He suggests that Germany be given control of Turkey in Asia in order that she may draw from the mineral resources of Asia Minor sufficient raw material to preserve her industries.

[1] Introduced by C. K. Leith.

French official sources indicate that the post-war industry in tungsten, tin, and phosphates will be chiefly in the hands of the Allies, and that efforts should be made to prevent Germany from participation in control of these industries.

These suggestions are interesting possibilities for post-war regulation of mineral industries. Nevertheless, we should remember that healthy industry will always be governed to a large extent by the laws of supply and demand. We must prevent Germany from becoming the dominant industrial market of the world, but the result should be attained not so much by choking German industry at its source as by fostering and sustaining our own industries until they can successfully compete with Germany in her own field. If each individual nation shall come to realize that she owes it both to herself and to the world to fully develop her resources and her efficiency, not selfishly, in order that she may swell her own power to the extermination of industrial development in other nations, but generously, so that each nation may fulfil the share of human welfare imposed on her by nature, then and then only the great war may bring forth lasting good to the human race.

Read in full from manuscript.

Discussion

Dr. E. S. Bastin: Miss Bliss has, I think, sounded a keynote for the future in the appeal for an unselfish use of our natural resources. "Economic independence" has acquired the force of a slogan during the war, and now at the close of the war is already being used as an argument for protective tariff legislation. In formulating our attitude toward these questions let us remember that our great part in the war has been conditioned not so much on the fact that our resources were adequate for our own needs as on the fact that they were *more* than adequate, so that we were able to contribute largely to the needs of our Allies. Further, our voluntary restriction of imports during the war, with its attendant efforts to further develop home resources, was designed to free ships for the transport of troops and supplies; it was not inaugurated for the purpose of developing home industries and will not be continued for such purposes alone. Great natural resources, like large personal inheritances, have no virtue except as they strengthen and ennoble the national character; unless they are properly used they build "fat," not "brawn." The great events of the past two years show nothing more clearly than the opportunities and duties of enlarged intercourse with the rest of the world, and trade is the material basis of such intercourse. The resources we cast on the waters in foreign trade may prove fully as important to our national welfare, and vastly more important to the world's welfare than those we consume at home.

Miss Eleanora F. Bliss: It should be borne in mind that France, in order to develop her recently acquired mineral resources, must have coal. The necessary coal can be drawn only from Germany. If Germany furnishes to France sufficient coal for complete development of French industry, she will be deficient in coal for her own needs. On the other hand, if France should export her iron and steel to Germany for treatment, the French iron and steel would suffer in the German market by competition with the product of the Luxemburg furnaces which is admitted to Germany duty free. The problem is essen-

tially how to furnish France with sufficient coal without unduly wrecking German industry.

Remarks were also made by Messrs. G. O. Smith, J. B. Umpleby, and W. H. Emmons, with reply by the author.

WAR-TIME DEVELOPMENT OF THE OPTICAL INDUSTRY

BY F. E. WRIGHT

(*Abstract*)

A brief description was given of the development and rapid expansion of the optical glass and instrument industry to meet war needs. Special reference was made to the methods adopted to accomplish this result and to solve the many problems, such as the manufacture of optical glass, the training of skilled operatives in precision optics, which confronted us on our entrance into the war.

Presented in abstract from notes.

Discussed by Prof. W. H. Emmons, with reply by the author.

GEOLOGIC AND PRESENT CLIMATES

BY MARSDEN MANSON [1]

Presented by title in the absence of the author.

CONDITIONS OF DEPOSITION OF SOME TERTIARY PETROLIFEROUS SEDIMENTS

BY AMADEUS W. GRABAU

(*Abstract*)

In a previous communication the author has discussed the interrelations of some oil-producing and oil-bearing formations of the North American Paleozoic. Continued study of the stratigraphy of oil-bearing formations has shown that at least the more important European Tertiary oil formations indicate deposition in more or less inclosed basins of the Black Sea and the Karabugas types, and that the source of the petroleum is to be sought in the abundant destruction of life chiefly of pelagic types, which were carried into these inclosed basins, where scavengers were absent. Such appears to be the origin of the petroleum of the Alsace-Lorraine basin, to which the author's field studies were confined, but a detailed consideration of the Tertiary stratigraphy of the Galician, Roumanian, and Caucasian regions indicates a similar origin for the petroleum deposits of those districts. The very general association of these petroleum-bearing strata with salt deposits is regarded as highly significant. That the diatomaceous sediments of the California oil fields are deposits in inclosed basins, free, because of the nature of the water, from animals which would devour the organic matter, rather than deposits in the deep sea, seems to

[1] Introduced by E. O. Hovey.

be indicated by the nature of the sediments as well as by the Tertiary history of the west coast region.

Presented by title at the request of the author.

PHOSPHATE ROCK AN ECONOMIC ARMY

BY R. W. STONE

(*Abstract*)

The United States is the largest producer of phosphate rock in the world. It has also been a heavy exporter, in pre-war years sending upward of a million tons annually to Europe. Second only to the United States in quantity of rock produced is Tunis, a French colony in North Africa. In 1913 the United States produced 3,000,000 tons of phosphate rock, Tunis 2,250,000 tons, and Algeria 460,000 tons, or nearly 6,000,000 tons as compared with about 1,000,000 for all other countries. During the war, German-owned phosphate deposits in islands of the Pacific were seized by England and Japan. There are now practically no phosphate rock deposits in the possession of neutral and enemy countries.

Before the war Germany used annually about 270,000 tons of phosphoric acid in the form of super-phosphates, over 90 of which was imported, and 375,000 tons of phosphatic slag, from iron ores used in steel-making. More than 40 per cent of the iron ore used by Germany was imported from Luxemburg, Sweden, and France. The balance was mined in Lorraine, which has now been restored to France.

Germany, therefore, is now dependent on her enemies for phosphoric acid, which she needs for intensive agriculture. Phosphate rock can therefore be used as a guard to keep the peace and force Germany to pay her bills.

Read in abstract from manuscript.

PREVAILING STRATIGRAPHIC RELATIONSHIPS OF THE BEDDED PHOSPHATE DEPOSITS OF EUROPE, NORTH AFRICA, AND NORTH AMERICA

BY A. W. GRABAU

(*Abstract*)

The great majority of the bedded phosphate deposits of all geological horizons occur along a plane of disconformity, and as a rule in association with calcareous bedrock, which is often secondarily phosphatized. This points to concentration of phosphatic material originally scattered widely through the missing formation. The paleogeographic significance of such deposits will be discussed and its application in searching for new phosphate horizons will be suggested.

Presented by title at the request of the author.

Session of Saturday Afternoon, December 28

The afternoon was devoted to a joint session with the Association of American Geographers, with its President, N. M. Fenneman, in the chair.

TITLES AND ABSTRACTS OF PAPERS PRESENTED AT THE AFTERNOON SESSION

PRINCIPLES IN THE DETERMINATION OF BOUNDARIES

ALBERT PERRY BRIGHAM

(*Abstract*)

The paper discusses the evolution of boundaries, which are recognized as features of maturing civilization and growing population. Two types of view are noted, one school favoring defensive and separative lines and the other, boundaries which shall be social and assimilative. Mountains, seas, deserts, and rivers represent four classes of boundaries as afforded by physical features or conditions. A survey of the several continents shows that such separative features are not as common or efficient as is supposed by many, and a similar conclusion follows on a historical study of well known features like the Pyrenees, the Alps, and the English Channel.

We are therefore compelled in the future to use more than in the past human factors in drawing boundaries. Among these race, language, and nationality are considered, the last named being by far the most important. Factors of social and economic bearing are also analyzed, such as the expansion of prolific peoples and expansions due to economic greed and dynastic ambition. Other correlated topics are the economic status of small nations, losses by emigration, and boundaries for economic equilibrium. France, Poland, and the coastal population veneers of the Near East are treated as samples of current European problems. The main conclusions are summarized as follows:

The present arrangement of human groups is a heritage from long existing biological conditions of dispersal, migration, and intermingling, complicated by the vagaries of the human will, as seen in lust of conquest, love of war, dynastic ambitions, and economic greed.

The necessity of bounding lines has come with the filling of the world's spaces, the pressure of population on resources, and the lifting and widening of the material standards of living.

Approximately 25 human groups in Europe show such unity of purpose and ideal, such community of interest, of history and of hopes, and each in such reasonable numbers, that they have embarked, or deserve to embark, on a career of nationality.

The world is now pretty well agreed that ruling houses are obsolete, that the interests of great powers are no more valid than those of small powers, and that economic equilibrium, or self-sufficiency in natural resources, does not outweigh the rights and desires of any truly national group.

Europe has an exceptional number of physical units which in primitive days could serve as the cradles of nations. In the advanced conditions and high densities of today, however, the number of physical compartments falls far short of the number of groups which properly wish independence.

Modern appliances for war have impaired the security once gained through physical barriers. Heights of land and waters of all kinds give important aid in war, but they do not fend off war. We cannot "destroy the germs of frontier dispute by drawing physical boundaries."

We must draw boundaries on defensible or separating lines if possible, but at all events to work substantial justice.

Read in abstract from manuscript.

Discussed by Professors W. M. Davis and Bailey Willis.

GEOGRAPHIC DESCRIPTIONS OF ARMY CANTONMENTS AND OF UNITED STATES BOUNDARY REGIONS

BY M. R. CAMPBELL

Presented by title in the absence of the author.

SIGNAL CORPS SCHOOL OF METEOROLOGY

BY OLIVER L. FASSIG [1]

(*Abstract*)

In the summer of 1918 a school of instruction was established at the Agricultural and Mechanical College of Texas, under authority of the Chief Signal Officer of the Army, for the purpose of training approximately 1,000 men in the applications of the science of meteorology to the operations of the war.

The first class consisted of 300 men, mostly recruited from among college men with several years' experience as engineers. The technical instruction, covering a period of two to three months, comprised daily lectures in meteorology or aerology; frequent cloud studies in the field; the construction and interpretation of weather maps; the preparation of forms and the making of daily observations of the weather, such as are made at all Weather Bureau stations of the first order; and field exercises in the use of a theodolite, a modified surveyor's transit, used to determine the paths of small rubber balloons filled with hydrogen, the movements of the balloon indicating the velocity and direction of the winds to great elevations above the earth's surface.

The high grade of the men composing the class made it possible to develop new mechanical devices and quick methods of reduction of observations for determining the ballistic wind for correcting long-range artillery fire. The projectiles fired from the big modern guns not only have a horizontal range of thirty to forty miles, but they traverse the atmosphere to heights of ten to fifteen miles and more. The wind velocities along the path of the projectile may vary from a few miles per hour to fifty or even a hundred miles, while the winds at an elevation of two or three miles may blow in a direction directly opposite to that at the earth's surface. For accurate long-range firing, it is obviously necessary to know the exact atmospheric conditions along the path of the projectile and to get this information quickly.

The instruction staff of the School of Meteorology consisted of: Dr. Oliver L. Fassig, U. S. Weather Bureau, Chief Instructor and Director; Dr. Charles F. Brooks, Yale University, Instructor in Meteorology; Lieut. William S. Bowen, Signal Reserve Corps, Instructor in Aerology; Mr. William T. Lathrop, U. S. Weather Bureau, Instructor in Meteorology.

At the time of the signing of the armistice, about 500 men had been trained as weather observers, 300 of whom were sent to France and 200 assigned to duty in this country at a score or more of flying fields, artillery fields, and balloon schools, for the purpose of supplying these units of the army with accurate information concerning actual atmospheric conditions or prospective weather conditions.

Read in abstract from manuscript.

[1] Introduced by N. M. Fenneman.

WORLD VIEW OF MINERAL WEALTH

BY JOSEPH B. UMPLEBY

(*Abstract*)

The desirability for a world view of mineral wealth has not been felt, until recently, as strongly in the United States as in the leading European countries, and consequently our mining literature is built largely around deposits in this country. At present, however, it is opportune to seek to form a world view of mineral wealth as a basis for expanding trade with foreign countries and as a guide in the wisest exploitation of our own resources.

Mineral commodities, manufactured and raw, represent about one-third of the total value of international trade. But, even more important than this, minerals are vanishing, whereas most other raw materials are renewable assets. They are also peculiarly localized in distribution and mutually dependent industrially.

The mineral production of a country or a continent, if viewed in the light of its industrial development and labor supply, may be taken as a general index of its relative mineral wealth. The value of the 1913 world output of the 30 leading mineral commodities may be taken as a basis of comparison. Of this amount the percentage contribution of the United States was 36; Germany, 15; United Kingdom, 11; Russia, 5; Union of South Africa, 4; Australia, 3, and smaller amounts for other countries. In any scheme of international agreements providing for pooling and allocation we should recognize clearly that the United States has more to contribute than any other nation.

Estimates of the world's mineral reserves are only available for coal and iron, but as tonnage is the great item in the distribution of industrial centers, they are the controlling factors. Together they represent over 90 per cent by weight of mineral production. Both the coal and iron reserves of the world occur predominantly in the North Atlantic drainage basin.

Consumption of mineral commodities, like production and reserves, is in countries tributary to the north Atlantic Ocean. Seventy-nine per cent of the 1913 output of eleven representative mineral commodities was consumed in the United States, Great Britain, Germany, and France. Thirty per cent of the total consumption was in the United States.

For centuries industry has centered about the north Atlantic and for centuries to come it is destined to continue here, its locus, however, moving from the eastern to the western shore.

Read in full from manuscript.

Discussed by Messrs. W. H. Emmons and G. O. Smith.

INTERNATIONALIZATION OF MINERAL RESOURCES

BY C. K. LEITH

(*Abstract*)

A brief outline of world movement of "minerals" is followed by discussion of:

(1) International movement under normal trade conditions.

(2) National control of imports and exports through tariff, bonus, embargo, or other measures, including war restrictions due to ship shortage.

(3) International control of imports and exports introduced as a war measure for some of the minerals, and possibly to be extended under any arrangement for a league of nations. The possibilities and results of international control, its purposes, its effect on world movement of minerals, the position of the United States in such an arrangement, reaction on domestic production and on our policy of making the United States independent in regard to mineral supplies. Conservation as a factor in internationalization.

Presented by title in the absence of the author.

COMMERCIAL CONTROL OF THE MINERAL RESOURCES OF THE WORLD

BY JOSIAH EDWARD SPURR

(*Abstract*)

During the war the problem of the supply of ores, both foreign and domestic, became a vital one, and it soon became evident that it was important to know in whose hands the supply of these mineral necessities rested. With the discovery of the network of German intrigue, it became necessary to scrutinize the control by German interests of mineral supplies and markets, and in so doing the investigators became aware of the vast influence not only of the German commercial combinations, but also of the similar control exercised by the industrial enterprises of other nations. A preliminary survey was, therefore, begun and is now nearly finished, and special pamphlets have been issued under the auspices of the Interior Department covering the field of the commercial control of the principal minerals in the world.

It is conceded that the natural boundaries for autonomous states are those of race, tongue, and geography; but the extent and forms of empires have been and will be determined by natural resources, especially of the metals.

Of all great nations, the United States has within its boundaries the greatest mineral wealth, and probably least of all nations has realized its political significance. History shows that the possession of great resources by a country is of little importance by itself; it is the *commercial* control which gives rise to power, wealth, and the growth of industrial civilizations. The commercial control of mineral and other natural resources is normally followed by political control.

One of the principal lessons to be learned from the series of individual mineral studies mentioned is that the United States Government must protect and encourage the investment of American capital in mineral wealth. It must do this in the United States, else we shall have our resources dominated commercially by foreign capital; and we must do it in Mexico, for example, else foreign capital will occupy the field and will threaten our political independence in the future in much the same way as if they had accomplished the same commercial domination in the United States. Only by recognizing and encouraging combinations of American capital engaged in mining can the well organized foreign combinations of capital be offset and checkmated.

The policy of our Government indicated for the future is to manage to best advantage such ores as we possess in exportable surplus, and to secure by careful forethought such ores as we do possess in quantity sufficient for our own needs.

It has been noted that the competition of combined commercial interests other than German exists under at least semi-official guidance, and that, for example, the policy of the English in this regard is a very deliberate one. This development is a natural one and we find the same impulse in American thought.

In some of the mineral commodities it is possible that there will soon develop a world shortage, with resulting sharp competition between the United States and its best friends, such as England and Japan. There is danger in this commercial competition, which easily leads to war. The only reasonable solution would seem to be for the rival houses to amalgamate. The plans for a league of nations, now under way, may fail on account of the many nations and diverse interests and ideals involved. It is, however, not only feasible, but imperative, that the three nations which stand abreast in the forefront of civilization should amalgamate and agree on a firm central policy looking forward toward reciprocity or free trade, so far as it is fair, among themselves. Treaties will do no good of themselves. Any league to be effective must be bound not only by a central judiciary, but by a central legislative body, executive council, and a central military or police force by land and sea.

This federation by itself would guarantee the world's peace, and other nations would be on probation and would be admitted one by one as they showed themselves desirous and competent.

Presented by title in the absence of the author.

MEXICAN PETROLEUM AND THE WAR

BY E. W. SHAW

(*Abstract*)

The part played by petroleum and its products in the great war is a subject of general discussion, but there seems to be agreement that this part was very essential both in comparison with other war minerals and in comparison with other elements that contributed toward success. The value of Mexican petroleum involves peculiar factors, though, like the value of other available oil supplies, it has been controlled mainly by quantity, quality, and accessibility.

The quantity factor has had the following outstanding features: The actual output of the country was large—roughly, one-tenth as great as the world output. Eight years ago the output of the country was scarcely one-twentieth as great as in 1918, and the fraction of the world's output was only about one per cent. Twenty years ago the fields were undiscovered. On the other hand, the aggregate capacity of the wells already drilled has differed from those of other regions in that it has always been far above the actual output; also if conditions of development had been as favorable as they are in some parts of the world there would have been many more wells drilled and a far greater supply of oil would have been available—perhaps twice as much as all the world is now producing. The country has the largest oil wells in the world, and the main part of the output has thus far come from a very few wells. Roughly, half of the output of the country in 1918 was used in connection with the domestic and military requirements of the United States, and of the capital invested in Mexican oil nearly two-thirds is American.

As to quality, the peculiar features of Mexican petroleum lie in the relatively low percentage of light distillates and the relatively high sulphur content. It furnishes little gasoline in comparison with its bulk, and this percentage has not been raised to a high figure through cracking processes. However, Mexico offers an immense reserve of fuel oil, though for fuel much of the oil needs an admixture of more fluid oil, or special burners adapted to its high viscosity. Its percentage of undesirable sulphur is reduced most readily by the addition of sulphur-free oil.

The accessibility depends on many considerations, including its distance from the points where it is refined and used and from the sources of labor and supplies, on the tankers, pipe-lines and other transportation facilities available, and on political conditions in and around the fields arising out of local disturbances, and the decrees issued by the Mexican Government involving high taxation (15 to 20 per cent), and nationalization or threatened "confiscation of private property and arbitrary deprivation of vested rights." If sufficient tankers had been available, the production for 1918 would have been five or ten times greater.

Presented by title in the absence of the author.

AMERICAN MAPPING IN FRANCE

BY GLENN S. SMITH [1]

Presented in abstract from notes.

THE AMERICAN TOPOGRAPHER IN THE ROLE OF ARTILLERY ORIENTATION OFFICER

BY F. E. MATTHES

Presented in full extemporaneously.

Discussed by Messrs. Glenn S. Smith, J. Russell Smith, H. F. Reid, G. O. Smith, and W. M. Davis.

President Cross, of the Geological Society of America, resumed the chair, the joint session dissolved, the members of the Association of American Geographers retiring to continue their own program in their usual meeting place, and the Geological Society of America took up its special papers again, as follows:

A METHOD OF AERIAL TOPOGRAPHIC MAPPING

BY FRED H. MOFFIT AND J. W. BAGLEY

Read in full from manuscript by the junior author.

In the discussion, Dr. R. B. Marshall, of the United States Geological Survey, gave some concrete examples of the accurate mapping which had been done by Messrs. Bagley and Moffit with their aeroplane camera.

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[1] Introduced by N. M. Fenneman.

A PLANE-TABLE FOR MILITARY MAPPING

BY ALAN M. BATEMAN

(*Abstract*)

During the teaching of military mapping at Yale University a plane-table equipment was designed, at a low cost, for instruction in that particular phase of mapping. It enables more effective results to be obtained than the equipment used in most training centers and described in the text-books.

Presented by title in the absence of the author.

SAND-CHROME DEPOSITS OF MARYLAND[1]

BY JOSEPH T. SINGEWALD, JR.

(*Abstract*)

Though competition put an end to rock-chrome mining in Maryland at about 1880, there has been a small production of sand-chrome concentrates to the present time. The output is exported to Europe, where it is used to set the colors of painting on fine porcelain ware. The Maryland deposits are capable of supplying this limited market indefinitely, but could not support a greatly augmented production.

Chemical analyses of several samples of the concentrates and of magnetic and non-magnetic portions into which they were separated yielded some interesting data concerning the characteristics of the spinel minerals found in the chrome-bearing serpentine areas of Maryland. Following is a brief summary of these results:

A spinel molecule, carrying an equivalent of only 29 per cent magnetite, may be highly magnetic if chromic oxide is in excess of alumina, whereas one carrying an equivalent of 26 per cent magnetite may be not at all magnetic if the alumina is in excess of chromic oxide. Since alumina reduces the magnetism of the spinel molecule, these figures indicate that a chromite containing no alumina might be highly magnetic if it contains an equivalent of less than 25 per cent magnetite. Such a chromite would appear to be magnetite in the field and might be disregarded in a search for chrome ore, yet it would analyze 51 per cent Cr_2O_3. On the other hand, a non-magnetic black spinel in a chromite-bearing region, which in the field would appear to be good chrome ore, might run so high in alumina and iron that the chromic oxide content of the ore would fall to less than 7 per cent.

These data point out the inadequacy of simple field tests in prospecting for chrome ore and the necessity of checking such observations by chemical analyses.

Read in full from manuscript.

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[1] Presented with permission of the State Geologist.

CARTERSVILLE POTASH SLATES; THEIR ECONOMIC RELATION TO CHEMICAL AND INDUSTRIAL POST-WAR DEVELOPMENT

BY T. POOLE MAYNARD

(*Abstract*)

The Cartersville potash slates are of such composition, geographic extent, thickness and easy accessibility, and liberation of the potash occurs at such low temperatures that these, together with other factors which relate to development, make possible the utilization of these materials as a source of potash after the war is over.

The presence of these deposits in the center of the area in the United States, where 90 per cent of the potash is consumed, together with low cost of production and relation to the source of the largest supply of the two chief acids, nitric and sulphuric, used in chemical industries, will bring about both chemical and agricultural development, which will have a very important bearing on the increase in production of agricultural products.

The origin, nature of the deposits, methods of extracting the potash, and history of development will be discussed.

Presented by title in the absence of the author.

ANTICLINAL THEORY, AS APPLIED TO SOME QUICKSILVER DEPOSITS

BY JOHAN AUGUST UDDEN

(*Abstract*)

In the Terlingua quicksilver district cinnabar ore occurs in its larger distribution in structures, such as anticlines, domes, and arrested monoclines, at stratigraphical levels where there is a change from porous rock below to more impervious formations above. Accumulation seems to have been governed by conditions similar to those which result in the accumulation of oil and gas, with this difference, that it occurs in favorable structures only in places where there has been fissuring or intrusion of igneous material. Most of the ore is found in joints, fissures, fault breccias, and contacts. These evidently have served as channels through which the mercurial vapors or, more probably, their solutions found outlet upward. The richest deposits have been found at horizons where the change between underlying and overlying rocks has been greatest, such as near the contact between the Georgetown (Edwards) and the Del Rio clay and between the Buda and the basal parts of the Eagle Ford. Conditions are described as they are known in four mines now worked and in four of the more important prospects in the area.

Presented in abstract from notes.

CRYSTALLINE GRAPHITE DEPOSITS OF ALABAMA

BY W. F. PROUTY

(*Abstract*)

The development of the crystalline graphite industry in Alabama has been phenomenal. In 1914 there were three producing plants. At the present time

there are twenty-eight. In 1917 Alabama, with fourteen plants, furnished 66 per cent by value of the production of crystalline graphite of the United States.

The graphite area in Alabama is confined largely to Clay, Coosa, and Chilton counties, in the Piedmont district. The mica schists in which the workable graphite beds occur is separated from the semicrystalline Ocoee phyllite to the west by a green schist of igneous origin and grades into a mica schist on the east with more frequent streaks of granitoid gneiss. The area in which workable graphite beds occur is approximately sixty miles long and has a maximum width of about five and a half miles. In one locality a cross-section of the field shows twenty workable beds, some of which are over 100 feet in thickness.

The ore is disseminated in a mica schist and seldom exceeds an average graphite content of 3½ per cent. The graphite is of sedimentary origin, though occasional thin veins and enrichments of graphite occur in the stringers of pegmatite or along the borders of the larger pegmatite "horses."

There are many processes of concentration in the various mills. Both the entirely wet and entirely dry processes are employed. Of the wet methods there are four distinct processes of water flotation and five methods of "oil flotation"—oil and water.

The chief attention of the graphite companies at the present time is directed toward the standardization of their products and the lowering of the cost of production, both of which are essential to the success of the industry.

Presented by title in the absence of the author.

FURTHER EVIDENCE OF THE AGE OF THE CRYSTALLINE AND SEMI-CRYSTALLINE ROCKS IN ALABAMA

BY W. F. PROUTY

(*Abstract*)

In 1903 Dr. E. A. Smith showed the presence of certain Carboniferous fossils in Ocoee slate area in Clay County, Alabama. During the past summer the writer further extended this known Carboniferous area to the foot of the Talladega Mountain, at Clairmont Springs. In connection with the fossiliferous black slate deposits there is an associated conglomerate which has every appearance of the Millstone grit as it occurs in the coal fields a few miles to the west of this region. This conglomerate is the same as that forming the main ridge of the Talladega Mountain or Blue Ridge in this part of Alabama.

Directly to the southeast from the known Carboniferous locality in the Ocoee slates there is a narrow belt of metamorphosed green schists which cuts at a sharp angle across the strike of the Carboniferous rock and gives every evidence of having been formed later than the unquestioned Corboniferous rock on the west.

In the crystalline belt southeast from the Carboniferous locality there are well defined belts and several smaller areas of phyllites which have every appearance of the Ocoee to the west. These areas not only carry a conglomerate which is similar to that in the Talladega Mountain and which is by inference Carboniferous, but they also have beds of amorphous graphite.

The southeastern portion of the crystalline rocks of Alabama is generally supposed to be older than that in the western portion. However, in one locality

near Chewacla there is strong evidence for believing the rocks to be of Paleozoic age. About two miles southeast from Opelika there occurs a ridge of what appears to be Knox chert associated with mica schist and gneisses. About a quarter of a mile west of this chert ridge there is a ten-foot bed of low-grade iron ore which strongly resembles the low-grade iron ores of the Clinton of the Birmingham region. About five miles southeast of Opelika and three miles southeast of Chewacla there is a long narrow strip of dolomitic marble which has on either side of it narrow strips of what appears to be Knox chert. To all appearances, this belt of dolomite and chert is infolded and overturned toward the west.

Presented by title in the absence of the author.

CONTRIBUTION TO THE ORIGIN OF DOLOMITE

BY W. A. TARR

(*Abstract*)

Field studies carried on in the Ozark area of Missouri during recent years have furnished evidence bearing on the time and place of dolomitization. The evidence favors the view advocated by Steidtmann that the magnesium carbonate is added to the calcium carbonate on the sea-bottom, probably immediately after the deposition of the calcium carbonate. The almost absolute purity of the dolomites in the Ozark area is favorable to his view that gradations do not exist between calcite and dolomite and favors the suggestion made below. Analyses of the dolomites show that they contain up to .85 per cent iron oxide, mostly FeO, and always much more iron than aluminum, thus accounting for the remarkably deep red soils over these dolomites. The dolomites in this area are shallow-water deposits in large part, showing all its usual features of such deposits.

Further studies made by mapping the dolomite areas according to the geologic period during which the dolomite was deposited have shown that these areas were occupied by broad, shallow, inclosed seas, in which there might have been a concentration of magnesium and other salts above that of normal sea-water. This concentration of salines and the probable increase in the amount of magnesium salts would greatly favor the rapid formation of dolomite. This would explain why practically pure limestones, with only 1 to 3 per cent of magnesium carbonate, are found interbedded with pure dolomites. The freshening of the water in the inclosed seas by influxes of normal sea-water would prevent the formation of dolomite until the concentration in salinity or in the magnesium content had again been brought about. Not a single occurrence has been found in the Cambrian and Ordovician dolomites of Missouri where the limestone grades into dolomite.

The work done to the present favors the marine origin of dolomite and the view that deposition occurred in shallow, inclosed seas where increased salinity or concentration of magnesium salts might occur.

Presented by title in the absence of the author.

MAGNESITE INDUSTRY

BY R. W. STONE

(*Abstract*)

Magnesite and its derived products are used in a variety of industries, the most essential of which is metallurgy. In the form of brick and grains, it has its greatest application as lining of open-hearth steel furnaces and other furnaces for refining metal. A considerable quantity of calcined magnesite is used in the manufacture of cement for exterior and interior plasters and for flooring.

Magnesite occurs both massive and crystalline, as veins and beds. The massive California variety occurring in veins is derived from the alteration of serpentine; the crystalline Washington variety results from the replacement of calcareous sedimentary rocks by magnesium-bearing solutions.

Magnesite is widely distributed throughout the world. Formerly Austria-Hungary and Greece supplied most of the American demand. Newly discovered deposits in Washington and greatly increased output in California, together with imports from Quebec, supplied the domestic need during the war. The manufacture of synthetic grain magnesite and of sintered dolomite and slag east of Chicago for refractory purposes, giving an advantage of several dollars in freight rates over magnesite from our only producing States, California and Washington, raises a question as to the permanence of the domestic magnesite industry at its present scale. Domestic material can not compete on the Atlantic coast with foreign magnesite at pre-war prices.

Presented in abstract from notes.

CERTAIN ASPECTS OF GLACIATION IN ALASKA

BY WARREN O. CROSBY

(*Abstract*)

The paper describes and discusses examples, believed to be typical, which tend to localize glacial overdeepening, and to show that valley broadening is by far the more important phase.

Presented by title in the absence of the author.

PAPERS TRANSFERRED TO PALEONTOLOGICAL SOCIETY

The following papers on stratigraphic and paleontologic geology were offered in regular course to the Geological Society, but were transferred to the Paleontological Society for reading on account of the crowded condition of the program:

HAROLD L. ALLING (introduced by H. L. Fairchild): Some problems of the Adirondack Precambrian.

HERVEY W. SHIMER: Permo-Triassic of northwestern Arizona.

GEORGE E. DORSEY (introduced by E. W. Berry): The stratigraphy and structure of the Newark system in Maryland and its relation to the Newark system of eastern North America.

GEORGE H. CHADWICK: Remarkable persistence of thin horizons.

George H. Chadwick: Portage stratigraphy in western New York.
Edward W. Berry: The age of certain plant-bearing beds and associated marine formations in South America.
Charles K. Swartz and Harvey Bassler: The typical section of the Allegheny formation.
Charles K. Swartz, W. A. Price, Jr., and Harvey Bassler: The stratigraphy and correlation of the Coal Measures of Maryland.
Bruce L. Clark: The Eocene divisions of California.

VOTE OF THANKS

On motion by Charles P. Berkey, a cordial vote of thanks was passed, expressing to the authorities of Johns Hopkins University and to the members of the local committee, Edward B. Mathews, chairman, the appreciation felt by the Society for facilities rendered and hospitality extended in connection with the Thirty-first Annual Meeting.

The business sessions adjourned.

ANNUAL DINNER

The customary annual subscription dinner of the Society was held at the Southern Hotel, beginning at 7 o'clock p. m., jointly with the Paleontological Society and the Association of American Geographers—one hundred and four members and guests participating. President Whitman Cross presided over the function and called on Dr. J. C. Merriam, incoming President, to speak for the future of the Society.

Dr. Henry M. Ami, Vice-President of the Geological Society of France, gave greetings from that sister organization, and Prof. William M. Davis spoke briefly on a "League of Nations for the Maintenance of Peace," concerning which he proposed shortly to send a petition to all members of the Society for their signatures.

At the close of Doctor Ami's remarks, the Secretary called the attention of the Society to the message which had been received at his office from Prof. E. de Margerie, Perpetual Secretary of the Geological Society of France, at the time America joined in the war.

CABLEGRAM TO SOCIÉTÉ GÉOLOGIQUE DE FRANCE

The Secretary was unanimously authorized to send the greetings of the Geological Society of America to the Geological Society of France, with felicitations over the coming of peace.[1]

[1] In conformity with these instructions, the following cablegram was sent on December 29:

"Geological Society America, annual meeting assembled, send warmest greetings Société Géologique France and best wishes for firm peace.

"(Signed) Hovey, *Secretary.*"

PRESIDENTIAL ADDRESS BY WHITMAN CROSS

President Cross then read his address as retiring President of the Society, entitled "Geology in the War and After."

VICE-PRESIDENTIAL ADDRESS BY GEORGE H. PERKINS

The address of President Cross was followed by the address of the retiring Vice-President of Section E of the American Association for the Advancement of Science, George H. Perkins, entitled "Physiography of Vermont."

Register of the Baltimore Meeting, 1918

FELLOWS

R. C. Allen
H. M. Ami
George H. Ashley
H. Foster Bain
Joseph Barrell
Florence Bascom
R. S. Bassler
Edson S. Bastin
Charles P. Berkey
S. W. Beyer
Edward W. Berry
Eliot Blackwelder
J. A. Bownocker
A. P. Brigham
H. A. Buehler
Rollin T. Chamberlin
John M. Clarke
H. F. Cleland
A. J. Collier
D. Dale Condit
A. R. Crook
Whitman Cross
H. P. Cushing
N. H. Darton
W. M. Davis
F. W. De Wolf
J. S. Diller
W. H. Emmons
H. L. Fairchild
N. M. Fenneman
A. F. Foerste
W. E. Ford
A. C. Gill
A. W. Grabau
H. E. Gregory
G. P. Grimsley
C. A. Hartnagel
D. F. Hewett
R. R. Hice
W. J. Holland
W. O. Hotchkiss
Ernest Howe
E. O. Hovey
Ellsworth Huntington
J. P. Iddings
George F. Kay
Arthur Keith
Edwin Kirk
Adolph Knopf
F. H. Knowlton
H. B. Kümmel
George F. Kunz
Waldemar Lindgren
G. F. Loughlin

S. W. McCallie
G. R. Mansfield
C. F. Marbut
R. B. Marshall
George C. Martin
E. B. Mathews
C. F. Matthes
O. E. Meinzer
W. C. Mendenhall
J. C. Merriam
George P. Merrill
Arthur M. Miller
W. J. Miller
H. D. Miser
F. H. Moffit
E. S. Moore
H. F. Osborn
Sidney Paige
G. H. Perkins
R. A. F. Penrose, Jr.
J. E. Pogue
W. Armstrong Price
W. F. Prouty
Harry F. Reid
W. N. Rice
John F. Rich
H. Ries
F. C. Schrader
C. Schuchert
Eugene Shaw
J. T. Singewald, Jr.
George Otis Smith
Philip S. Smith
J. W. Spencer
J. Stanley-Brown
T. W. Stanton
L. W. Stephenson
James H. Stoller
R. W. Stone
George W. Stose
Chas. K. Swartz
A. C. Trowbridge
J. B. Tyrrell
E. O. Ulrich
J. A. Udden
J. B. Umpleby
G. Van Ingen
Frank R. Van Horn
T. W. Vaughan
T. L. Walker
T. L. Watson
L. G. Westgate
Edgar T. Wherry
I. C. White
David White
Bailey Willis
Geo. R. Wieland
M. E. Wilson
Chas. W. Wright
F. E. Wright

FELLOWS-ELECT

C. Wythe Cooke
E. De Golyer
Frank F. Grout
Roswell H. Johnson
G. S. Rogers

There were also 34 visitors who registered.

OFFICERS, CORRESPONDENTS. AND FELLOWS OF THE GEOLOGICAL SOCIETY OF AMERICA

OFFICERS FOR 1919

President:

John C. Merriam, Berkeley, Calif.

Vice-Presidents:

R. A. F. Penrose, Jr., Philadelphia, Pa.
Herbert E. Gregory, New Haven, Conn.
Robert T. Jackson, Peterborough, N. H.

Secretary:

Edmund Otis Hovey, American Museum of Natural History, New York, N. Y.

Treasurer:

Edward B. Mathews, Johns Hopkins University, Baltimore, Md.

Editor:

J. Stanley-Brown, 26 Exchange Place, New York, N. Y.

Councilors:

(Term expires 1919)

Arthur L. Day, Washington, D. C.
William H. Emmons, Minneapolis, Minn.

(Term expires 1920)

Joseph Barrell, New Haven, Conn.
R. A. Daly, Cambridge, Mass.

(Term expires 1921)

William S. Bayley, Urbana, Ill.
Eugene W. Shaw, Washington, D. C.

MEMBERSHIP, 1919

CORRESPONDENTS

Barrois, Charles, Lille, France. December, 1909.
Brögger, W. C., Christiania, Norway. December, 1909.
Capellini, Giovanni, Bologna, Italy. December, 1910.
De Geer, Baron Gerhard, Stockholm, Sweden. December, 1910.
Geikie, Sir Archibald, Hasslemere, England. December, 1909.
Heim, Albert, Zürich, Switzerland. December, 1909.
Kayser, Emanuel, Marburg, Germany. December, 1909.
Kilian, W., Grenoble, France. December, 1912.
Teall, J. J. H., London, England. December, 1912.
Tietze, Emil, Vienna, Austria. December, 1910.

FELLOWS

* Indicates Original Fellows (see article III of Constitution)

Abbe, Cleveland, Jr., U. S. Weather Bureau, Washington, D. C. August, 1899.
Adams, Frank Dawson, McGill University, Montreal, Canada. Dec., 1889.
Adams, George I., 17 San T'iao Hutung, Peking, China. December, 1902.
Alden, William C., U. S. Geological Survey, Washington, D. C. Dec., 1909.
Aldrich, Truman H., Birmingham, Ala. May, 1889.
Allan, John A., University of Alberta, Strathcona, Canada. December, 1914.
Allen, R. C., State Geological Survey, Lansing, Mich. December, 1911.
Ami, Henry M., Strathcona Park, Ottawa, Canada. December, 1889.
Anderson, Frank M., State Mining Bureau, 2604 Aetna St., Berkeley, Calif. December, 1902.
Anderson, Robert V., Menlo Park, Calif. December, 1911.
Arnold, Ralph, 923 Union Oil Building, Los Angeles, Calif. December, 1904.
Ashley, George Hall, U. S. Geological Survey, Washington, D. C. Aug., 1895.
Atwood, Wallace Walter, Harvard University, Cambridge, Mass. Dec., 1909.
Bagg, Rufus Mather, Jr., 7 Brokaw Place, Appleton, Wis. December, 1896.
Bain, H. Foster, Box 994, American P. O., Shanghai, China. December, 1895.
Baker, Manley Benson, School of Mining, Kingston, Ontario. Dec., 1911.
Baldwin, S. Prentiss, 2930 Prospect Ave., Cleveland, Ohio. August, 1895.
Ball, Sydney H., 71 Broadway, New York City. December, 1905.
Bancroft, Joseph A., McGill University, Montreal, Canada. December, 1914.
Barbour, Erwin Hinckley, University of Nebraska, Lincoln, Neb. Dec., 1896.
Barrell, Joseph, Yale University, New Haven, Conn. December, 1902.
Barton, George H., Boston Society of Natural History, Boston, Mass. August, 1890.
Bartsch, Paul, U. S. National Museum, Washington, D. C. December, 1917.
Bascom, Florence, Bryn Mawr College, Bryn Mawr, Pa. August, 1894.
Bassler, Ray Smith, U. S. National Museum, Washington, D. C. Dec., 1906.
Bastin, Edson S., U. S. Geological Survey, Washington, D. C. Dec., 1909.
Bateman, Alan Mara, Yale University, New Haven, Conn. December, 1916.
Bayley, William S., University of Illinois, Urbana, Ill. December, 1888.
*Becker, George F., U. S. Geological Survey, Washington, D. C.
Beede, Joshua W., 404 West 38th St., Austin, Texas. December, 1902.

Berkey, Charles P., Columbia University, New York, N. Y. August, 1901.
Berry, Edward Wilber, Johns Hopkins University, Baltimore, Md. Dec., 1909.
Beyer, Samuel Walker, Iowa Agricultural College, Ames, Iowa. Dec., 1896.
Blackwelder, Eliot, University of Illinois, Urbana, Ill. December, 1908.
Boutwell, John M., 1323 De la Vine St., Santa Barbara, Calif. Dec., 1905.
Bowen, Charles F., U. S. Geological Survey, Washington, D. C. Dec., 1916.
Bowen, N. L., Queen's University, Kingston, Ont., Canada. December, 1917.
Bownocker, John Adams, Ohio State University, Columbus, Ohio. Dec., 1904.
*Branner, John C., Leland Stanford, Jr., University, Stanford Univ., Calif.
Branson, Edwin Bayer, University of Missouri, Columbia, Mo. Dec., 1911.
Bretz, J. H., University of Chicago, Chicago, Ill. December, 1917.
Brigham, Albert Perry, Colgate University, Hamilton, N. Y. December, 1893.
Brock, Reginald W., Univ. of British Columbia, Vancouver, B. C. Dec., 1904.
Brooks, Alfred Hulse, U. S. Geological Survey, Washington, D. C. Aug., 1899.
Brown, Barnum, American Museum of Natural History, New York, N. Y. December, 1910.
Brown, Charles Wilson, Brown University, Providence, R. I. Dec., 1908.
Brown, Thomas Clachar, Bryn Mawr College, Bryn Mawr, Pa. Dec., 1915.
Buehler, Henry Andrew, Rolla, Mo. December, 1909.
Burling, Lancaster D., Geological Survey of Canada, Ottawa, Canada. December, 1917.
Burwash, Edward M. J., Victoria College, Toronto, Canada. December, 1916.
Butler, Bert S., U. S. Geological Survey, Washington, D. C. December, 1912.
Butler, G. Montague, College of Mines, Tucson, Arizona. December, 1911.
Butts, Charles, U. S. Geological Survey, Washington, D. C. December, 1912.
Calhoun, Fred Harvey Hall, Clemson College, S. C. December, 1909.
Calkin, Frank C., U. S. Geological Survey, Washington, D. C. Dec., 1914.
Campbell, Henry D., Washington and Lee Univ., Lexington, Va. May, 1889.
Campbell, Marius R., U. S. Geological Survey, Washington, D. C. Aug., 1892.
Campos, Luiz Filippe G. de, Geological Survey of Brazil, Rio de Janeiro, Brazil. December, 1917.
Camsell, Charles, Geological Survey, British Columbia Branch, 510 Pacific Building, Vancouver, B. C. December, 1914.
Capps, Stephen R., Jr., U. S. Geological Survey, Washington, D. C. Dec., 1911.
Carman, J. Ernest, Ohio State University, Columbus, Ohio. December, 1917.
Carney, Frank, 1644 New Hampshire St., Lawrence, Kans. December, 1908.
Case, Ermine C., University of Michigan, Ann Arbor, Mich. December, 1901.
Chadwick, George H., University of Rochester, Rochester, N. Y. Dec., 1911.
Chamberlin, Rollin T., University of Chicago, Chicago, Ill. December, 1913.
*Chamberlin, T. C., University of Chicago, Chicago, Ill.
Claghorn, Clarence Raymond, Claghorn, Pa. August, 1891.
Clapp, Charles H., Montana School of Mines, Butte, Mont. December, 1914.
Clapp, Frederick G., 120 Broadway, New York, N. Y. December, 1905.
Clark, Bruce L., Bacon Hall, Univ. of California, Berkeley, Calif. Dec., 1918.
Clarke, John Mason, Albany, N. Y. December, 1897.
Cleland, Herdman F., Williams College, Williamstown, Mass. Dec., 1905.
Clements, J. Morgan, 20 Broad St., New York City. December, 1894.
Cobb, Collier, University of North Carolina, Chapel Hill, N. C. Dec., 1894.
Coleman, Arthur P., Toronto University, Toronto, Canada. December, 1896.
Collie, George L., Beloit College, Beloit, Wis. December, 1897.

Collier, Arthur J., U. S. Geological Survey, Washington, D. C. June, 1902.
Condit, D. Dale, U. S. Geological Survey, Washington, D. C. December, 1916.
Cook, Charles W., University of Michigan, Ann Arbor, Mich. Dec., 1915.
Cooke, C. Wythe, U. S. Geological Survey, Washington, D. C. Dec., 1918.
Coste, Eugene, 1943 11th St., West, Calgary, Alberta, Canada. Dec., 1906.
Crawford, Ralph Dixon, 1050 Tenth St., Boulder, Colo. December, 1916.
Crook, Alja R., State Museum of Natural History, Springfield, Ill. Dec., 1898.
*Crosby, William O., Massachusetts Institute of Technology, Boston, Mass.
Cross, Whitman, U. S. Geological Survey, Washington, D. C. May, 1889.
Culver, Garry E., 310 Center Ave., Stevens Point, Wis. December, 1891.
Cumings, Edgar R., Indiana University, Bloomington, Ind. August, 1901.
*Cushing, Henry P., Western Reserve University, Cleveland, Ohio.
Daly, Reginald A., Harvard University, Cambridge, Mass. December, 1905.
Dana, Edward Salisbury, Yale University, New Haven, Conn. Dec., 1908.
*Darton, Nelson H., U. S. Geological Survey, Washington, D. C.
*Davis, William M., 31 Hawthorne St., Cambridge, Mass.
Day, Arthur Louis, Corning Glass Works, Corning, N. Y. December, 1909.
Day, David T., 1333 F St. N. W., Washington, D. C. August, 1891.
Dean, Bashford, Columbia University, New York, N. Y. December, 1910.
De Golyer, E. L., 65 Broadway, New York City. December, 1918.
Deussen, Alexander, 504 Stewart Bldg., Houston, Texas. December, 1916.
De Wolf, Frank Wilbridge, Urbana, Ill. December, 1909.
Dickerson, Roy E., 114 Burnett Ave., San Francisco, Calif. December, 1918.
*Diller, Joseph S., U. S. Geological Survey, Washington, D. C.
d'Invilliers, Edward V., 518 Walnut St., Philadelphia, Pa. December, 1888.
Dodge, Richard E., Dodge Farm, Washington, Conn. August, 1897.
Drake, Noah Fields, Fayetteville, Arkansas. December, 1898.
Dresser, John A., 701 Eastern Townships Bank Bldg., Montreal, Canada. December, 1906.
*Dumble, Edwin T., 2003 Main St., Houston, Texas.
Eakle, Arthur S., University of California, Berkeley, Calif. December, 1899.
Eckel, Edwin C., Munsey Building, Washington, D. C. December, 1905.
*Emerson, Benjamin K., 529 West 111th St., New York City.
Emmons, William H., Univ. of Minnesota, Minneapolis, Minn. Dec., 1912.
*Fairchild, Herman L., University of Rochester, Rochester, N. Y.
Farrington, Oliver C., Field Museum of Natural History, Chicago, Ill. December, 1895.
Fenneman, Nevin M., University of Cincinnati, Cincinnati, Ohio. Dec., 1904.
Fenner, Clarence N., Geophysical Laboratory, Washington, D. C. Dec., 1911.
Fisher, Cassius Asa, 711 Ideal Building, Denver, Colo. December, 1908.
Foerste, August F., 129 Wroe Ave., Dayton, Ohio. December, 1899.
Ford, William E., Sheffield Scientific School, New Haven, Conn. Dec., 1915.
Fuller, Myron L., Box 1109, Dallas, Texas. December, 1898.
Galpin, Sidney L., 620½ Sherman Ave., East, Hutchinson, Kans. Dec., 1917.
Gane, Henry Stewart, Wonalancet, New Hampshire. December, 1896.
Gardner, James H., 510 New Daniel Bldg., Tulsa, Oklahoma. December, 1911.
George, Russell D., University of Colorado, Boulder, Colo. December, 1906.
Gill, Adam Capen, Cornell University, Ithaca, N. Y. December, 1888.
Glenn, L. C., Vanderbilt University, Nashville, Tenn. June, 1900.
Goldman, Isaac Marcus, U. S. Geol. Survey, Washington, D. C. Dec., 1916.

GOLDTHWAIT, JAMES WALTER, Dartmouth College, Hanover, N. H. Dec., 1909.

GORDON, CHARLES H., University Library, University of Tennessee, Knoxville. Tenn. August, 1893.

GORDON, CLARENCE E., Massachusetts Agricultural College, Amherst, Mass. December, 1913.

GOULD, CHARLES N., 1218 Colcord Bldg., Oklahoma City, Okla. Dec., 1904.

GRABAU, AMADEUS W., Columbia University, New York, N. Y. December, 1898.

GRANGER, WALTER, American Museum of Natural History, New York, N. Y. December, 1911.

GRANT, ULYSSES SHERMAN, Northwestern Univ., Evanston, Ill. Dec., 1890.

GRASTY, JOHN SHARSHALL, Box 458, Charlottesville, Va. December, 1911.

GRATON, LOUIS C., Harvard University, Cambridge, Mass. December, 1913.

GREGORY, HERBERT E., Yale University, New Haven, Conn. August, 1901.

GREENE, FRANK COOK, 30 North Yorktown St., Tulsa, Okla. December, 1917.

GRIMSLEY, GEORGE P., 31st and Calvert Sts., Gilman 3-B, Baltimore, Md. August, 1895.

GROUT, FRANK F., University of Minnesota, Minneapolis, Minn. Dec., 1918.

GURLEY, WILLIAM F. E. R., University of Chicago, Chicago, Ill. Dec., 1914.

HALBERSTADT, BAIRD, Pottsville, Pa. December, 1909.

HARDER, E. C., U. S. Geological Survey, Washington, D. C. December, 1918.

HARRIS, GILBERT D., Cornell University, Ithaca, N. Y. December, 1903.

HARRISON, JOHN BURCHMORE, Georgetown, British Guiana. June, 1902.

HARTNAGEL, CHRIS A., Education Building, Albany, N. Y. December, 1913.

HASTINGS, JOHN B., 1480 High St., Denver, Colo. May, 1889.

*HAWORTH, ERASMUS, University of Kansas, Lawrence, Kans.

HENNEN, RAY V., West Virginia Geol. Survey, Morgantown, W. Va. Dec., 1914.

HERSHEY, OSCAR H., Kellogg, Idaho. December, 1909.

HEWETT, DONNEL F., U. S. Geological Survey, Washington, D. C. Dec., 1916.

HICE, RICHARD R., Beaver, Pa. December, 1903.

*HILL, ROBERT T., 612 American Exchange Bldg., Dallas, Texas.

HILLS, RICHARD C., Denver, Colo. August, 1894.

HINDS, HENRY, Sinclair Oil and Gas Company, Tulsa, Okla. December, 1912.

HINTZE, FERDINAND FRIIS, Lehigh Univ., South Bethlehem, Pa. Dec., 1917.

*HITCHCOCK, CHARLES H., 2376 Oahu Ave., Honolulu, Hawaiian Islands.

HOBBS, WILLIAM H., University of Michigan, Ann Arbor, Mich. August, 1891.

*HOLBROOK, LEVI, P. O. Box 536, New York, N. Y.

HOLDEN, ROY J., Virginia Polytechnic Institute, Blacksburg, Va. Dec., 1914.

HOLLAND, WILLIAM JACOB, Carnegie Museum, Pittsburgh, Pa. December, 1910.

HOLLICK, ARTHUR, Staten Island Association of Arts and Sciences, New Brighton, S. I. August, 1898.

HOPKINS, THOMAS C., Syracuse University, Syracuse, N. Y. December, 1894.

HOTCHKISS, WILLIAM OTIS, State Geological Survey, Madison, Wis. Dec., 1911.

*HOVEY, EDMUND OTIS, American Museum of Natural History, New York, N. Y.

HOWE, ERNEST, Litchfield, Conn. December, 1903.

HUBBARD, GEORGE D., Oberlin College, Oberlin, Ohio. December, 1914.

HUDSON, GEORGE H., Plattsburg Normal School, Plattsburg, N. Y. Dec., 1917.

HUNT, WALTER F., University of Michigan, Ann Arbor, Mich. December, 1914.

HUNTINGTON, ELLSWORTH, 222 Highland St., Milton, Mass. December, 1906.

HUSSAKOF, LOUIS, American Museum of Natural History, New York, N. Y. December, 1910.

HYDE, J. E., Western Reserve University, Cleveland, Ohio. December, 1916.
IDDINGS, JOSEPH P., Brinklow, Md. May, 1889.
JACKSON, A. WENDELL, 9 Desbrosses St., New York, N. Y. December, 1888.
JACKSON, ROBERT T., Peterborough, N. H. August, 1894.
JAGGAR, THOMAS AUGUSTUS, JR., Hawaiian Volcano Observatory, Territory of Hawaii, U. S. A. December, 1906.
JEFFERSON, MARK S. W., Michigan State Normal College, Ypsilanti, Mich. December, 1904.
JEFFREY, EDWARD C., Harvard University, Cambridge, Mass. December, 1914.
JOHANNSEN, ALBERT, University of Chicago, Chicago, Ill. December, 1908.
JOHNSON, DOUGLAS WILSON, Columbia University, New York, N. Y. Dec., 1906.
JOHNSON, ROSWELL H., 306 State Hall, University of Pittsburgh, Pittsburgh, Pa. December, 1918.
JOHNSTON, WILLIAM ALFRED, Geological Survey, Ottawa, Canada. Dec., 1916.
JULIEN, ALEXIS A., South Harwich, Mass. May, 1889.
KATZ, FRANK JAMES, U. S. Geological Survey, Washington, D. C. Dec., 1912.
KAY, GEORGE FREDERICK, State Univ. of Iowa, Iowa City, Iowa. Dec., 1908.
KEITH, ARTHUR, U. S. Geological Survey, Washington, D. C. May, 1889.
*KEMP, JAMES F., Columbia University, New York, N. Y.
KEYES, CHARLES ROLLIN, 944 Fifth St., Des Moines, Iowa. August, 1890.
KINDLE, EDWARD M., Victoria Memorial Museum, Ottawa, Canada. Dec., 1905.
KIRK, CHARLES T., Box 1592, Tulsa, Okla. December, 1915.
KIRK, EDWIN, U. S. Geological Survey, Washington, D. C. December, 1912.
KNIGHT, CYRIL WORKMAN, Toronto, Ontario, Canada. December, 1911.
KNOPF, ADOLPH, U. S. Geological Survey, Washington, D. C. December, 1911.
KNOWLTON, FRANK H., U. S. National Museum, Washington, D. C. May, 1889.
KRAUS, EDWARD HENRY, University of Michigan, Ann Arbor, Mich. June, 1902.
KÜMMEL, HENRY B., Trenton, N. J. December, 1895.
*KUNZ, GEORGE F., 401 Fifth Ave., New York, N. Y.
LADD, GEORGE E., 6109 Brookville Road, Chevy Chase, Md. August, 1891.
LAHEE, FREDERIC H., Massachusetts Institute of Technology, Cambridge, Mass. December, 1917.
LAMBE, LAWRENCE MORRIS, Department of Mines, Ottawa, Canada. Dec., 1911.
LANDES, HENRY, University of Washington, University Station, Seattle, Wash. December, 1908.
LANE, ALFRED C., Tufts College, Mass. December, 1889.
LARSEN, ESPER S., JR., U. S. Geological Survey, Washington, D. C. Dec., 1914.
LAWSON, ANDREW C., University of California, Berkeley, Cal. May, 1889.
LEE, WILLIS THOMAS, U. S. Geological Survey, Washington, D. C. Dec., 1903.
LEES, JAMES H., Iowa Geological Survey, Des Moines, Iowa. December, 1914.
LEITH, CHARLES K., University of Wisconsin, Madison, Wis. Dec., 1902.
LEONARD, ARTHUR G., State University of North Dakota, Grand Forks, N. Dak. December, 1901.
LEVERETT, FRANK, Ann Arbor, Mich. August, 1890.
LEWIS, JOSEPH VOLNEY, Rutgers College, New Brunswick, N. J. Dec., 1906.
LIBBEY, WILLIAM, Princeton University, Princeton, N. J. August, 1899.
LINDGREN, WALDEMAR, Massachusetts Institute of Technology, Cambridge, Mass. August, 1890.
LISBOA, MIGUEL A. R., Caixa postal 829, Ave. Rio Branco 46-V, Rio de Janeiro, Brazil. December, 1913.

Little, Homer P., Colby College, Waterville, Maine. December, 1918.
Logan, William N., Indiana University, Bloomington, Ind. December, 1917.
Loomis, Frederick Brewster, Amherst College, Amherst, Mass. Dec., 1909.
Louderback, George D., University of California, Berkeley, Cal. June, 1902.
Loughlin, Gerald F., U. S. Geological Survey, Washington, D. C. Dec., 1916.
Low, Albert P., Department of Mines, Ottawa, Canada. December, 1905.
Lull, Richard Swann, Yale University, New Haven, Conn. December, 1909.
Lupton, Charles T., Cosden Oil and Gas Company, Tulsa, Okla. Dec., 1916.
McCallie, Samuel Washington, Atlanta, Ga. December, 1909.
McCaskey, Hiram D., U. S. Geological Survey, Washington. D. C. Dec., 1904.
McConnell, Richard G., Geological and Natural History Survey of Canada, Ottawa, Canada. May, 1889.
MacDonald, Donald F., 713 Chronicle Bldg., Houston, Texas. Dec., 1915.
Macfarlane, James Rieman, Woodland Road, Pittsburgh, Pa. August, 1891.
McInnes, William, Geological and Natural History Survey of Canada, Ottawa, Canada. May, 1889.
McKellar, Peter, Fort William, Ontario, Canada. August, 1890.
Mansfield, George R., 2067 Park Rd., N. W., Washington, D. C. Dec., 1909.
Marbut, Curtis F., Bureau of Soils, Washington, D. C. August, 1897.
Marsters, Vernon F., 316 Rialto Bldg., Kansas City, Mo. August, 1892.
Martin, George C., U. S. Geological Survey, Washington, D. C. June, 1902.
Martin, Lawrence, University of Wisconsin, Madison, Wis. December, 1909.
Mather, Kirtley F., Denison University, Granville, Ohio. December, 1918.
Mathews, Edward B., Johns Hopkins University, Baltimore, Md. Aug., 1895.
Matson, George C., U. S. Geological Survey, Washington, D. C. Dec., 1918.
Matthes, Francois E., U. S. Geol. Survey, Washington, D. C. Dec., 1914.
Matthew, W. D., American Museum of Natural History, New York, N. Y. December, 1903.
Maynard, Thomas Poole, 1622 D. Hurt Bldg., Atlanta, Ga. December, 1914.
Mead, Warren Judson, University of Wisconsin, Madison, Wis. Dec., 1916.
Meinzer, Oscar E., U. S. Geological Survey, Washington, D. C. Dec., 1916.
Mendenhall, Walter C., U. S. Geol. Survey, Washington, D. C. June, 1902.
Merriam, John C., University of California, Berkeley, Calif. August, 1895.
Merrill, George P., U. S. National Museum, Washington, D. C. Dec., 1888.
Merwin, Herbert E., Geophysical Laboratory, Washington, D. C. Dec., 1914.
Miller, Arthur M., State University of Kentucky, Lexington, Ky. Dec., 1897.
Miller, Benjamin L., Lehigh University, South Bethlehem, Pa. Dec., 1904.
Miller, Willet G., Toronto, Canada. December, 1902.
Miller, William John, Smith College, Northampton, Mass. December, 1909.
Miser, Hugh D., U. S. Geological Survey, Washington, D. C. December, 1916.
Moffit, Fred Howard, U. S. Geological Survey, Washington, D. C. Dec., 1912.
Molengraaf, G. A. F., Technical High School, Delft, Holland. December, 1913.
Montgomery, Henry, Painesville, Ohio. December, 1904.
Moore, Elwood S., Pennsylvania State College, State College, Pa. Dec., 1911.
Munn, Malcolm John, Clinton Bldg., Tulsa, Okla. December, 1909.
*Nason, Frank L., West Haven, Conn.
Newland, David Hale, Albany, N. Y. December, 1906.
Newsom, John F., Leland Stanford, Jr., University, Stanford University, Calif. December, 1899.
Noble, Levi F., Valyermo, Calif. December, 1916.

Norton, William H., Cornell College, Mount Vernon, Iowa. December, 1895.
Norwood, Charles J., State University, Lexington, Ky. August, 1894.
Ogilvie, Ida Helen, Barnard College, Columbia University, New York, N. Y. December, 1906.
O'Hara, Cleophas C., South Dakota School of Mines, Rapid City, S. Dak. December, 1904.
Ohern, Daniel Webster, University of Oklahoma, Norman, Okla. Dec., 1911.
Oliveira, E. P. de, Geol. Survey of Brazil, Rio de Janeiro, Brazil. Dec., 1918.
Osborn, Henry F., American Museum of Natural History, New York, N. Y. August, 1894.
Pack, Robert W., U. S. Geological Survey, Washington, D. C. Dec., 1916.
Paige, Sidney, U. S. Geological Survey, Washington, D. C. December, 1911.
Palache, Charles, Harvard University, Cambridge, Mass. August, 1897.
Parks, William A., University of Toronto, Toronto, Canada. Dec., 1906.
*Patton, Horace B., 817 Fifteenth St., Golden, Colo.
Peck, Frederick B., Lafayette College, Easton, Pa. August, 1901.
Penrose, Richard A. F., Jr., 460 Bullitt Bldg., Philadelphia, Pa. May, 1889.
Perkins, George H., University of Vermont, Burlington, Vt. June, 1902.
Perry, Joseph H., 276 Highland St., Worcester, Mass. December, 1888.
Phalen, William C., U. S. Bureau of Mines, Washington, D. C. Dec., 1912.
Phillips, Alexander H., Princeton University, Princeton, N. J. Dec., 1914.
Pirsson, Louis V., Yale University, New Haven, Conn. August, 1894.
Pogue, Joseph E., Northwestern University, Evanston, Ill. December, 1911.
Pratt, Joseph H., North Carolina Geol. Survey, Chapel Hill, N. C. Dec., 1898.
Price, William A., Jr., Box 192, Morgantown, W. Va. December, 1916.
Prindle, Louis M., U. S. Geological Survey, Washington, D. C. Dec., 1912.
Prouty, William F., University of Alabama, University, Ala. Dec., 1911.
*Pumpelly, Raphael, Newport, R. I.
Ransome, Frederick L., U. S. Geol. Survey, Washington, D. C. August, 1895.
Raymond, Percy Edward, Museum of Comparative Zoölogy, Cambridge, Mass. December, 1907.
Reeds, Chester A., American Museum of Natural History, New York, N. Y. December, 1913.
Reger, David B., Box 816, Morgantown, W. Va. December, 1918.
Reid, Harry Fielding, Johns Hopkins University, Baltimore, Md. Dec., 1892.
Reinecke, Leopold, Geological Survey, Ottawa, Canada. December, 1916.
Rice, William North, Wesleyan University, Middletown, Conn. August, 1890.
Rich, John Lyon, 96 Chestnut St., Cooperstown, N. Y. December, 1912.
Richardson, Charles H., Syracuse University, Syracuse, N. Y. Dec., 1899.
Richardson, George B., U. S. Geol. Survey, Washington, D. C. Dec., 1908.
Ries, Heinrich, Cornell University, Ithaca, N. Y. December, 1893.
Riggs, Elmer S., Field Museum of Natural History, Chicago, Ill. Dec., 1911.
Robinson, Henry Hollister, Hopkins Hall, New Haven, Conn. Dec., 1916.
Rogers, Austin F., Stanford University, Calif. December, 1918.
Rogers, G. S., U. S. Geological Survey, Washington, D. C. December, 1918.
Rose, Bruce, Geological Survey, Ottawa, Canada. December, 1916.
Rowe, Jesse Perry, University of Montana, Missoula, Mont. December, 1911.
Ruedemann, Rudolf, Albany, N. Y. December, 1905.
Rutledge, John Joseph, Experiment Station, Pittsburgh, Pa. Dec., 1911.
St. John, Orestes H., 1141 Twelfth St., San Diego, Calif. May, 1889.

Sales, Reno H., Anaconda Copper Mining Company, Butte, Mon. Dec., 1916.
Sayles, Robert Wilcox, Harvard University, Chestnut Hill, Mass. Dec., 1917.
*Salisbury, Rollin D., University of Chicago, Chicago, Ill.
Sardeson, Frederick W., Univ. of Minnesota, Minneapolis, Minn. Dec., 1892.
Savage, Thomas Edmund, University of Illinois, Urbana, Ill. December, 1907.
Schaller, Waldemar T., U. S. Geol. Survey, Washington, D. C. Dec., 1918.
Schofield, S. J., Geological Survey of Canada, Ottawa, Canada. Dec., 1918.
Schrader, Frank C., U. S. Geological Survey, Washington, D. C. Aug., 1901.
Schuchert, Charles, Yale University, New Haven, Conn. August, 1895.
Schultz, Alfred R., Hudson, Wis. December, 1912.
Scott, William B., Princeton University, Princeton, N. J. August, 1892.
Seaman, Arthur E., Michigan College of Mines, Houghton, Mich. Dec., 1904.
Sellards, Elias H., Tallahassee, Fla. December, 1905.
Seña, Joaquim Candido da Costa, State School of Mines, Ouro Preto, Brazil. December, 1908.
Shaler, Millard K., 5 Montagne Du Parc, Brussels, Belgium. Dec., 1914.
Shannon, Charles W., Oklahoma Geol. Survey, Norman, Okla. Dec., 1918.
Shattuck, George Burbank, Vassar College, Poughkeepsie, N. Y. Aug., 1899.
Shaw, Eugene W., U. S. Geological Survey, Washington, D. C. Dec., 1912.
Shedd, Solon, State College of Washington, Pullman, Wash. December, 1904.
Shepard, Edward M., 1403 Benton Ave., Springfield, Mo. August, 1901.
Shimek, Bohumil, University of Iowa, Iowa City, Iowa. December, 1904.
Shimer, Hervey Woodburn, Massachusetts Institute of Technology, Cambridge, Mass. December, 1910.
Siebenthal, Claude E., U. S. Geol. Survey, Washington, D. C. Dec., 1912.
*Simonds, Frederick W., University of Texas, Austin, Texas.
Sinclair, William John, Princeton University, Princeton, N. J. Dec., 1906.
Singewald, Joseph T., Johns Hopkins University, Baltimore, Md. Dec., 1911.
Sloan, Earle, Charleston, S. C. December, 1908.
Smith, Burnett, Syracuse University, Skaneateles, N. Y. December, 1911.
Smith, Carl, Box 1136, Tulsa, Okla. December, 1912.
*Smith, Eugene A., University of Alabama, University, Ala.
Smith, George Otis, U. S. Geological Survey, Washington, D. C. Aug., 1897.
Smith, Philip S., U. S. Geological Survey, Washington, D. C. Dec., 1909.
Smith, Warren Du Pré, University of Oregon, Eugene, Ore. December, 1909.
Smith, W. S. Tangier, 640 Tennyson Ave., Palo Alto, Calif. June, 1902.
*Smock, John C., Hudson, N. Y.
Smyth, Charles H., Jr., Princeton University, Princeton, N. J. Aug., 1892.
Smyth, Henry L., Harvard University, Cambridge, Mass. August, 1894.
Soper, Edgar K., Port of Spain, Trinidad, B. W. I., P. O. Box 175. Dec., 1918.
Speight, Robert, Christ Church, Canterbury College, New Zealand. Dec., 1916.
Spencer, Arthur Coe, U. S. Geological Survey, Washington, D. C. Dec., 1896.
*Spencer, J. W., 2019 Hillyer Place, Washington, D. C.
Springer, Frank, U. S. National Museum, Washington, D. C. December, 1911.
Spurr, Josiah E., Bullitt Bldg., Philadelphia, Pa. December, 1894.
Stanley-Brown, Joseph, 26 Exchange Place, New York, N. Y. August, 1892.
Stanton, Timothy W., U. S. National Museum, Washington, D. C. Aug., 1891.
Stauffer, Clinton R., Univ. of Minnesota, Minneapolis, Minn. Dec., 1911.
Stebinger, Eugene, Jr., U. S. Geological Survey, Washington, D. C. Dec., 1916.
Steidtmann, Edward, University of Wisconsin, Madison, Wis. Dec., 1916.

Stephenson, Lloyd W., U. S. Geol. Survey, Washington, D. C. Dec., 1911.
*Stevenson, John J., 215 West 101st St., New York, N. Y.
Stoller, James Hough, Union College, Schenectady, N. Y. December, 1917
Stone, Ralph Walter, U. S. Geological Survey, Washington, D. C. Dec., 1912.
Stose, George Willis, U. S. Geological Survey, Washington, D. C. Dec., 1908
Stout, Wilber, Geological Survey of Ohio, Columbus, Ohio. December, 1918
Swartz, Charles K., Johns Hopkins University, Baltimore, Md. Dec., 1908.
Taber, Stephen, University of South Carolina, Columbia, S. C. Dec., 1914
Taff, Joseph A., 781 Flood Building, San Francisco, Cal. August, 1895
Talbot, Mignon, Mount Holyoke College, South Hadley, Mass. Dec., 1913
Talmage, James E., 47 E. So. Temple St., Salt Lake City, Utah. Dec., 1897.
Tarr, William Arthur, University of Missouri, Columbia, Mo. Dec., 1917.
Taylor, Frank B., Fort Wayne, Ind. December, 1895.
*Todd, James E., 905 Missouri Ave., Lawrence, Kans.
Tolman, Cyrus Fisher, Jr., Leland Stanford, Jr., University, Stanford University, Calif. December, 1909.
Tomlinson, Charles Weldon, 714 Ideal Bldg., Denver, Colo. December, 1917.
Trowbridge, Arthur C., 602 West 190th St., New York City. December, 1913.
*Turner, Henry W., 209 Alaska Commercial Bldg., San Francisco, Calif.
Twenhofel, William H., University of Wisconsin, Madison, Wis. Dec., 1913.
Twitchell, Mayville W., State Geological Survey, Trenton, N. J. Dec., 1911.
Tyrrell, Joseph B., Confederation Life Bldg., Toronto, Canada. May, 1889.
Udden, Johan A., University of Texas, Austin, Texas. August, 1897.
Ulrich, Edward O., U. S. Geological Survey, Washington, D. C. Dec., 1903.
Umpleby, Joseph B., U. S. Geological Survey, Washington, D. C. Dec., 1913.
*Upham, Warren, Minnesota Historical Society, Saint Paul, Minn.
Van Horn, F. R., Case School of Applied Science, Cleveland, Ohio. Dec., 1898.
van Ingen, Gilbert, Princeton University, Princeton, N. J. December, 1904.
Van Tuyl, Francis M., Colorado School of Mines, Golden, Colo. Dec., 1917.
Vaughan, T. Wayland, U. S. Geol. Survey, Washington, D. C. August, 1896.
Veatch, Arthur Clifford, 19 Grosvenor Gardens, S. W. I., London, England. December, 1906.
*Vogdes, Anthony W., 2425 First St., San Diego, Calif.
*Wadsworth, M. Edward, School of Mines, Univ. of Pittsburgh, Pittsburgh, Pa.
*Walcott, Charles D., Smithsonian Institution, Washington, D. C.
Walker, Thomas L., University of Toronto, Toronto, Canada. Dec., 1903.
Warren, Charles H., Massachusetts Institute of Technology, Boston, Mass. December, 1901.
Washington, Henry Stephens, Geophysical Laboratory, Washington, D. C. August, 1896.
Watson, Thomas L., University of Virginia, Charlottesville, Va. June, 1900.
Weaver, Charles E., University of Washington, Seattle, Wash. Dec., 1913.
Weed, Walter H., 29 Broadway, New York, N. Y. May, 1889.
Wegemann, Carroll H., U. S. Geol. Survey, Washington, D. C. Dec., 1912.
Weidman, Samuel, Wisconsin Geological and Natural History Survey, Madison, Wis. December, 1903.
Weller, Stuart, University of Chicago, Chicago, Ill. June, 1900.
Westgate, Lewis G., Ohio Wesleyan University, Delaware, Ohio. Aug., 1894.
Wherry, Edgar T., Bureau of Chemistry, Washington, D. C. Dec., 1915.
White, David, U. S. National Museum, Washington, D. C. May, 1889.

*White, Israel C., Morgantown, W. Va.
Wieland, George Reber, Yale University, New Haven, Conn. December, 1910.
Wilder, Frank A., North Holston, Smyth County, Va. December, 1905.
*Williams, Edward H., Jr., Woodstock, Vt.
Williams, Ira A., Oregon Bureau of Mines and Geology, 417 Oregon Bldg., Portland, Ore. December, 1905.
Williams, Merton Yarwood, Geological Survey, Ottawa, Canada. Dec., 1916.
Willis, Bailey, Leland Stanford, Jr., University, Calif. December, 1889.
Wilson, Alfred W. G., Department of Mines, Ottawa, Canada. June, 1902.
Wilson, Morley Evans, Geological Survey, Ottawa, Canada. December, 1916.
Winchell, Alexander N., University of Wisconsin, Madison, Wis. Aug., 1901.
*Winchell, Horace Vaughn, First National Society Bldg., Minneapolis, Minn.
*Winslow, Arthur, 131 State St., Boston, Mass.
Wolff, John E., Harvard University, Cambridge, Mass. December, 1889.
Woodman, Joseph E., New York University, New York, N. Y. Dec., 1905.
Woodward, Robert S., Carnegie Institution of Washington, Washington, D. C. May, 1889.
Woodworth, Jay B., Harvard University, Cambridge, Mass. December, 1895.
Wright, Charles Will, Ingurtosu, Arbus, Sardinia, Italy. December, 1909.
Wright, Frederic E., Geophysical Laboratory, Carnegie Institution, Washington, D. C. December, 1903.
*Wright, G. Frederick, Oberlin Theological Seminary, Oberlin, Ohio.
Young, George A., Geological Survey of Canada, Ottawa, Canada. Dec., 1905.
Ziegler, Victor, Colorado School of Mines, Golden, Colo. December, 1916.

CORRESPONDENTS DECEASED

Credner, Herman. Died July 22, 1913.
Michel-Lévy, A. Died September, 1911.
Rosenbusch, H. Died January 20, 1914.
Suess, Edward. Died April 20, 1914.
Tschernyschew, Th. Died Jan. 15, 1914.
Zirkel, Ferdinand. Died June 11, 1912.

FELLOWS DECEASED

* Indicates Original Fellow (see article III of Constitution)

*Ashburner, Chas. A. Died Dec. 24, 1889.
Barlow, Alfred E. Died May 28, 1914.
Beecher, Charles E. Died Feb. 14, 1904.
Bell, Robert. Died June 18, 1917.
Bickmore, Albert S. Died Aug. 12, 1914.
Blake, Wm. Phipps. Died May 21, 1910.
Bowman, Amos. Died June 18, 1894.
Brown, Amos P. Died Oct. 9, 1917.
Buckley, Ernest R. Died Jan. 19, 1912.
Cairnes, D. D. Died June 14, 1917.
*Calvin, Samuel. Died April 17, 1911.
Carpenter, Frank R. Died April 1, 1910.
*Chapin, J. H. Died March 14, 1892.
Clark, William B. Died July 27, 1917.
*Claypole, Edward W. Died Aug. 17, 1901.
*Comstock, Theo. B. Died July 26, 1915.
Cook, George H. Died Sept. 22, 1889.
*Cope, Edward D. Died April 12, 1897.
Castillo, Antonio Del. Died Oct.28,1895.
*Dana, James D. Died April 14, 1895.
Davis, Charles A. Died April 9, 1916.
Dawson, George M. Died March 2, 1901.
Dawson, Sir J. Wm. Died Nov. 19, 1899.
Derby, Orville A. Died Nov. 27, 1915.
Drysdale, Chas. W. Died July 10, 1917.
Dutton, Clarence E. Died Jan. 4, 1912.
*Dwight, Wm. B. Died Aug. 29, 1906.
Eastman, Chas. R. Died Sept. 28, 1918.
*Eldridge, George H. Died June 29, 1905.
*Emmons, Samuel F. Died March 28, 1911.
Fontaine, Wm. M. Died April 29, 1913.
*Foote, Albert E. Died October 10, 1895.
*Frazer, Persifor. Died April 7, 1909.
*Fuller, Homer T. Died Aug. 14, 1908.
*Gilbert, Grove K. Died May 1, 1918.
Giroux, N. J. Died November 30, 1891.
Hague, Arnold. Died May 14, 1917.
*Hall, Christopher W. Died May 10,1911.
*Hall, James. Died August 7, 1898.
Hatcher, John B. Died July 3, 1904.

*Hay, Robert. Died December 14, 1895.
Hayes, C. Willard. Died Feb. 9, 1916.
*Heilprin, Angelo. Died July 17, 1907.
Hilgard, Eugene W. Died Jan. 8, 1916.
Hill, Frank A. Died July 13, 1915.
*Holmes, Joseph A. Died July 13, 1915.
Honeyman, David. Died October 17, 1889.
*Howell, Edwin E. Died April 16, 1911.
*Hovey, Horace C. Died July 27, 1914.
Hunt, Thomas S. Died Feb. 12, 1892.
*Hyatt, Alpheus. Died Jan. 15, 1902.
Irving, John D. Died July 26, 1918.
Jackson, Thomas M. Died Feb. 3, 1912.
*James, Joseph F. Died March 29, 1897.
Knight, Wilbur C. Died July 28, 1903.
Lacoe, Ralph D. Died February 5, 1901.
Laflamme, J. C. K. Died July 6, 1910.
Langton, Daniel W. Died June 21, 1909.
*Le Conte, Joseph. Died July 6, 1901.
*Lesley, J. Peter. Died June 2, 1903.
Loughridge, Robt. H. Died July 1, 1917.
McCalley, Henry. Died Nov. 20, 1904.
*McGee, W J. Died September 4, 1912.
Marcy, Oliver. Died March 19, 1899.
Marsh, Othniel C. Died March 18, 1899.
Mell, P. H. Died October 12, 1918.
*Merrill, Fred. J. H. Died Nov. 29, 1916.
Mills, James E. Died July 25, 1901.
*Nason, Henry B. Died January 17, 1895.
*Neff, Peter. Died May 11, 1903.
*Newberry, John S. Died Dec. 7, 1892.
Niles, William H. Died Sept. 12, 1910.
*Orton, Edward. Died October 16, 1899.
*Osborn, Amos O. Died March, 1911.
*Owen, Richard. Died March 24, 1890.
Penfield, Samuel L. Died Aug. 14, 1906.
Penhallow, David P. Died Oct. 20, 1910.
*Platt, Franklin. Died July 24, 1900.
Pettee, William H. Died May 26, 1904.
*Powell, John W. Died Sept. 23, 1902.
*Prosser, Chas. S. Died Sept. 11, 1916.
Purdue, A. H. Died Dec. 12, 1917.
*Russell, Israel C. Died May 1, 1906.
*Safford, James M. Died July 3, 1907.
*Schaeffer, Charles. Died Nov. 23, 1903.
Seely, H. M. Died May 4, 1917.
*Shaler, Nathaniel S. Died Apr. 10, 1906.
Sutton, William J. Died May 9, 1915.
Tarr, Ralph S. Died March 21, 1912.
Tight, William G. Died Jan. 15, 1910.
*Van Hise, C. R. Died Nov. 19, 1918.
Wachsmuth, Chas. Died Feb. 7, 1896.
Weston, Thomas C. Died July 20, 1910.
White, Theodore G. Died July 7, 1901.
*Whitfield, Robt. P. Died April 6, 1910.
*Williams, George H. Died July 12, 1894.
*Williams, J. Francis. Died Nov. 9, 1891.
*Williams, H. S. Died July 31, 1918.
Wilmott, Arthur B. Died May 8, 1914.
*Winchell, Alex. Died Feb. 19, 1891.
*Winchell, Newton. Died May 1, 1914.
Wright, Albert A. Died April 2, 1905.
Yeates, William S. Died Feb. 19, 1908.

Summary

Correspondents	10
Original Fellows	38
Elected Fellows	384
Membership	432
Deceased Correspondents	6
Deceased Fellows	103

Constitution and By-Laws

REFERENCES TO ADOPTION AND CHANGES

The provisional Constitution under which the Society was organized was approved August 15, 1888, and adopted December 27, 1888 (see Bulletin, volume 1, pages 7-8). These rules were elaborated and the revised Constitution and By-Laws were adopted December 27, 1889 (volume 1, pages 536, 571-578).

Several minor changes have been made in these rules, which are on record in the Bulletin as follows: Changes in the Constitution: December, 1894, volume 6, page 432; December, 1897, volume 9, page 400; December, 1909, volume 21, page 19. Changes in the By-Laws: December, 1891, volume 3, page 470; December, 1893, volume 5, pages 553-554; December, 1894, volume 6, page 432; December, 1903, volume 14, page 535; December, 1909, volume 21, page 19.

CONSTITUTION

Article I

NAME

This Society shall be known as The Geological Society of America.

Article II

OBJECT

The object of this Society shall be the promotion of the Science of Geology in North America.

Article III

MEMBERSHIP

The Society shall be composed of Fellows, Correspondents, and Patrons.

1. Fellows shall be persons who are engaged in geological work or in teaching geology.

Fellows admitted without election under the provisional Constitution shall be designated as Original Fellows on all lists or catalogues of the Society.

2. Correspondents shall be persons distinguished for their attainments in Geological Science and not resident in North America.

3. Patrons shall be persons who have bestowed important favors upon the Society.

4. Fellows alone shall be entitled to vote or hold office in the Society.

Article IV

OFFICERS

1. The officers of the Society shall consist of a President, First, Second, and Third Vice-Presidents, a Secretary, a Treasurer, an Editor, and six Councilors.

These officers, together with the Presidents for the next preceding three years, shall constitute an Executive Committee, which shall be called the Council.

2. The President shall discharge the usual duties of a presiding officer at all meetings of the Society and of the Council. He shall take cognizance of the acts of the Society and of its officers, and cause the provisions of the Constitution and By-Laws to be faithfully carried into effect.

3. The First Vice-President shall assume the duties of President in case of the absence or disability of the latter. The Second Vice-President shall assume the duties of President in case of the absence or disability of both the President and First Vice-President. The Third Vice-President shall assume the duties of President in case of the absence or disability of the President and the First and Second Vice-Presidents.

4. The Secretary shall keep the records of the proceedings of the Society, and a complete list of the Fellows, with the dates of their election and disconnection with the Society. He shall also be the secretary of the Council.

The Secretary shall cooperate with the President in attention to the ordinary affairs of the Society. He shall attend to the preparation, printing and mailing of circulars, blanks and notifications of elections and meetings. He shall superintend other printing ordered by the Society or by the President, and shall have charge of its distribution, under the direction of the Council.

The Secretary, unless other provision be made, shall also act as Editor of the publications of the Society, and as Librarian and Custodian of the property.

5. The Treasurer shall have the custody of all funds of the Society. He shall keep account of receipts and disbursements in detail, and this shall be audited as hereinafter provided.

6. The Editor shall supervise all matters connected with the publication of the transactions of the Society under the direction of the Council.

7. The Council is clothed with executive authority and with the legislative powers of the Society in the intervals between its meetings; but no extraordinary act of the Council shall remain in force beyond the next following stated meeting without ratification by the Society. The Council shall have control of the publications of the Society, under provisions of the By-Laws and of resolutions from time to time adopted. They shall receive nominations for Fellows, and, on approval by them, shall submit such nominations to the Society for action. They shall have power to fill vacancies *ad interim* in any of the offices of the Society.

8. *Terms of office.*—The President and Vice-Presidents shall be elected annually, and shall not be eligible to re-election more than once until after an interval of three years after retiring from office.

The Secretary, Treasurer, and Editor shall be eligible to re-election without limitation.

The term of office of the Councilors shall be three years; and these officers shall be so grouped that two shall be elected and two retire each year. Councilors retired shall not be re-eligible till after the expiration of a year.

Article V

VOTING AND ELECTIONS

1. All elections shall be by ballot. To elect a Fellow, Correspondent or Patron, or impose any special tax, shall require the assent of nine-tenths of all Fellows voting.

2. Voting by letter may be allowed.

3. *Election of Fellows.*—Nominations for fellowship may be made by two Fellows according to a form to be provided by the Council. One of these Fellows must be personally acquainted with the nominee and his qualifications for membership. The Council will submit the nominations received by them, if approved, to a vote of the Society in the manner provided in the By-Laws. The result may be announced at any stated meeting; after which notice shall be sent out to Fellows elect.

4. *Election of officers.*—Nominations for office shall be made by the Council. The nominations shall be submitted to a vote of the Society in the same manner as nominations for fellowship. The results shall be announced at the Annual Meeting; and the officers thus elected shall enter upon duty at the adjournment of the meeting.

Article VI

MEETINGS

1. The Society shall hold at least one stated meeting a year, in the winter season. The date and place of the Winter Meeting shall be fixed by the Council, and announced each year within three months after the adjournment of the preceding Winter Meeting. The program of each meeting shall be determined by the Council, and announced beforehand, in its general features. The details of the daily sessions shall also be arranged by the Council.

2. The Winter Meeting shall be regarded as the Annual Meeting. At this, elections of officers shall be declared, and the officers elect shall enter upon duty at the adjournment of the meeting.

3. Special meetings may be called by the Council, and must be called upon the written request of twenty Fellows.

4. Stated meetings of the Council shall be held coincidently with the stated meetings of the Society. Special meetings may be called by the President at such times as he may deem necessary.

5. *Quorum.*—At meetings of the Society a majority of those registered in attendance shall constitute a quorum. Five shall constitute a quorum of the Council.

Article VII

PUBLICATION

The serial publications of the Society shall be under the immediate control of the Council.

Article VIII

SECTIONS

Any group of Fellows representing a particular branch of geology may, with consent of the Council, organize as a section of the Society with separate constitution and by-laws, provided that nothing in such constitution and by-laws conflict with the Constitution and By-Laws of the Geological Society of America, in letter or spirit, and provided that such constitution and by-laws and all amendments thereto shall have been approved by the Council.

Article IX

AMENDMENTS

1. This Constitution may be amended at any annual meeting by a three-fourths vote of all the Fellows, provided that the proposed amendment shall have been submitted in print to all Fellows at least three months previous to the meeting.

2. By-laws may be made or amended by a majority vote of the Fellows present and voting at any annual meeting, provided that printed notice of the proposed amendment or by-law shall have been given to all Fellows at least three months before the meeting.

BY-LAWS

Chapter I

OF MEMBERSHIP

1. No person shall be accepted as a Fellow unless he pay his initiation fee, and the dues for the year, within three months after notification of his election. The initiation fee shall be ten (10) dollars and the annual dues ten (10) dollars, the latter payable on or before the annual meeting in advance; but a single prepayment of one hundred fifty (150) dollars shall be accepted as commutation for life. A Fellow in good standing, however, who has paid annual dues for not less than fifteen (15) years may commute further dues and become a Life Fellow by making a single payment of one hundred (100) dollars.

2. The sums paid in commutation of dues shall be covered into the Publication Fund.

3. An arrearage in payment of annual dues shall deprive a Fellow of the privilege of taking part in the management of the Society and of receiving the publications of the Society. An arrearage continuing over two (2) years shall be construed as notification of withdrawal.

4. Any person eligible under Article III of the Constitution may be elected Patron upon the payment of one thousand (1,000) dollars to the Publication Fund of the Society.

Chapter II

OF OFFICIALS

1. The President shall countersign, if he approves, all duly authorized accounts and orders drawn on the Treasurer for the disbursement of money.

2. The Secretary, until otherwise ordered by the Society, shall perform the duties of Editor, Librarian, and Custodian of the property of the Society.

3. The Society may elect an Assistant Secretary.

4. The Treasurer shall give bonds, with two good sureties approved by the Council, in the sum of five thousand dollars, for the faithful and honest performance of his duties and the safe-keeping of the funds of the Society. He may deposit the funds in bank at his discretion, but shall not invest them

without authority of the Council. His accounts shall be balanced as on the thirtieth day of November of each year.

5. In the selection of Councilors the various sections of North America shall be represented as far as practicable.

6. The minutes of the proceedings of the Council shall be subject to call by the Society.

7. The Council may transact its business by correspondence during the intervals between its stated meetings; but affirmative action by a majority of the Council shall be necessary in order to make action by correspondence valid.

Chapter III

OF ELECTION OF MEMBERS

1. Nominations for fellowship may be proposed at any time on blanks to be supplied by the Secretary.

2. The *form* for the nomination of Fellows shall be as follows:

In accordance with his desire, we respectfully nominate for Fellow of the Geological Society of America:

Full name; degrees; address; occupation; branch of Geology now engaged in, work already done and publications made.

(Signed by at least two Fellows.)

The form when filled is to be transmitted to the Secretary.

3. The Secretary will bring all nominations before the Council, and the Council will signify its approval or disapproval of each.

4. At least a month before one of the stated meetings of the Society the Secretary will mail a printed list of all approved nominees to each Fellow, accompanied by such information as may be necessary for intelligent voting; but an informal list of the candidates shall be sent to each Fellow at least two weeks prior to distribution of the ballots.

5. The Fellows receiving the list will signify their approval or disapproval of each nominee, and return the lists to the Secretary.

6. At the next stated meeting of the Council the Secretary will present the lists and the Council will canvass the returns.

7. The Council, by unanimous vote of the members in attendance, may still exercise the power of rejection of any nominee whom new information shows to be unsuitable for fellowship.

8. At the next stated meeting of the Society the Council shall declare the results.

9. Correspondents and Patrons shall be nominated by the Council, and shall be elected in the same manner as Fellows.

Chapter IV

OF ELECTION OF OFFICERS

1. The Council shall prepare a list of nominations for the several offices, which list will constitute the regular ticket. The ticket must be approved by a majority of the entire Council. The nominee for President shall not be a member of the Council. One of the nominees for vice-president shall be the

nominee for the presidency of the Paleontological Society, which has been organized as a section under Article VIII of the Constitution.

2. The list shall be mailed to the Fellows, for their information, at least nine months before the Annual Meeting. Any five Fellows may forward to the Secretary other nominations for any or all offices. All such nominations reaching the Secretary at least 40 days before the Annual Meeting shall be printed, together with the names of the nominators, as special tickets. The regular and special tickets shall then be mailed to the Fellows at least 25 days before the Annual Meeting.

3. The Fellows will send their ballots to the Secretary in double envelopes, the outer envelope bearing the voter's name. At the Winter Meeting of the Council, the Secretary will bring the returns of ballots before the Council for canvass, and during the Winter Meeting of the Society the Council shall declare the result.

4. In case a majority of all the ballots shall not have been cast for any candidate for any office, the Society shall by ballot at such Winter Meeting proceed to make an election for such office from the two candidates having the highest number of votes.

Chapter V

of financial methods

1. No pecuniary obligation shall be contracted without express sanction of the Society or the Council. But it is to be understood that all ordinary, incidental, and running expenses have the permanent sanction of the Society, without special action.

2. The creditor of the Society must present to the Treasurer a fully itemized bill, certified by the official ordering it, and approved by the President. The Treasurer shall then pay the amount out of any funds not otherwise appropriated, and the receipted bill shall be held as his voucher.

3. At each annual meeting, the President shall call upon the Society to choose two Fellows, not members of the Council, to whom shall be referred the books of the Treasurer, duly posted and balanced to the close of November thirtieth, as specified in the By-Laws, Chapter II, clause 4. The Auditors shall examine the accounts and vouchers of the Treasurer, and any member or members of the Council may be present during the examination. The report of the Auditors shall be rendered to the Society before the adjournment of the meeting, and the Society shall take appropriate action.

Chapter VI

of publications

1. The publications are in charge of the Council and under its control.

2. One copy of each publication shall be sent to each Fellow, Correspondent, and Patron, and each author shall receive thirty (30) copies of his memoir.

Chapter VII

of the publication fund

1. The Publication Fund shall consist of donations made in aid of publica-

tion, and of the sums paid in commutation of dues, according to the By-Laws, Chapter I, clause 2.

2. Donors to this fund, not Fellows of the Society, in the sum of two hundred dollars, shall be entitled, without charge, to the publications subsequently appearing.

Chapter VIII

OF ORDER OF BUSINESS

1. The Order of Business at Winter Meetings shall be as follows:
   (1) Call to order by the presiding officer.
   (2) Introductory ceremonies.
   (3) Report of the Council (including report of the officers).
   (4) Appointment of the Auditing Committee.
   (5) Declaration of the vote for officers, and election by the meeting in case of failure to elect by the Society through transmitted ballots.
   (6) Declaration of the vote for Fellows.
   (7) Deferred business.
   (8) New business.
   (9) Announcements.
   (10) Necrology.
   (11) Reading of scientific papers.

2. At an adjourned session the order shall be resumed at the place reached on the previous adjournment, but new business will be in order before the reading of scientific papers.

3. At the Summer Meeting the items of business under numbers (3), (4), (5), (10) shall be omitted.

4. At any Special Meeting the order of business shall be numbers (1), (2), (3), (9), followed by the special business for which the meeting was called.

Publication Rules of the Geological Society of America

(Adopted by the Council April 21, 1891; Revised April 30, 1894, May, 1904, and February 5, 1910)

General Provisions

Section 1. The Council shall annually appoint from their own number a Publication Committee, consisting of the Secretary, the Treasurer, the Editor, and two others, whose duties shall be to determine the disposition of matter offered for publication, except as provided in section 12; to determine the expediency, in view of the financial condition of the Society, of publishing any matter accepted on its merits; to exercise general oversight of the matter and manner of publication; to determine the share of the cost of publication (including illustrations) to be borne by the author when it becomes necessary to divide cost between the Society and the author; to adjudicate any questions relating to publication that may be raised from time to time by the Editor or by the Fellows of the Society; and in general to act for the Council in all matters pertaining to publication. (Cons., Art. IV, 7; Art. VII; By-Laws, chap. VI).

2. The duties of the Editor are to receive material offered for publication; to examine and submit it, with estimates of cost, to the Publication Committee; to publish all material accepted by the Council or Publication Committee; to revise proofs in connection with authors; to prepare lists of contents and general indexes; to audit bills for printing and illustrating; and to perform all other duties connected with publication not assigned to other officers. (Cons., Art. IV, 6; Rules, Sec. 16.)

3. The duties of the Secretary include the preparation of a record of the proceedings of each meeting of the Society in form for publication, and the custody, distribution, sale, exchange or other authorized disposition of the publications. (Cons., Art. IV, 4; By-Laws, chap. II, 2.)

4. Special committees may be appointed by the Council or the Publication Committee to examine and report on any matter offered for publication. (Rules, Sec. 11.)

The Bulletin

TITLE AND GENERAL CHARACTER

5. The Society shall publish a serial record of its work entitled "Bulletin of the Geological Society of America."

6. The Bulletin shall be published in quarterly parts, consecutively paged for each volume. The parts shall be suitably designated and each shall bear a title setting forth the contents and authorship, the seal and imprint of the Society and the date of publication.

7. The closing quarterly part of each volume shall contain an index, paged consecutively with the body of the volume; and it shall be accompanied by a volume title-page and lists of contents and illustrations, together with lists of the publications of the Society and such other matter as the Publication Committee may deem necessary, all arranged under Roman pagination.

MATTER OF THE BULLETIN

8. The matter published in the Bulletin shall comprise (1) communications presented at meetings by title or otherwise; (2) communications or memoirs not presented before the Society; (3) abstracts of papers read before the Society, prepared or revised for publication by authors; (4) reports of discussions held before the Society, prepared or revised for publication by authors; (5) proceedings of the meetings of the Society prepared by the Secretary; (6) plates, maps, and other illustrations necessary for the proper understanding of communications; (7) lists of Officers and Fellows, Constitution, By-Laws, resolutions of permanent character, rules relating to procedure, to publication, and to other matters, etcetera, and (8) indexes, title-pages, and lists of contents for each volume.

9. Abstracts, reports of discussion, or other matter purporting to emanate from any author shall not be published unless prepared or revised by the author.

10. Manuscript designed for publication in the Bulletin must be complete as to copy for text and illustration, except by special arrangement between the author and the Council or Publication Committee; it must be perfectly legible (preferably typewritten) and preceded by a table of contents (section 15). The cost of necessary revision of copy or reconstruction of illustrations shall be assessed on the author.

11. The Editor shall examine matter designated for publication, and shall prepare an itemized estimate of the cost of publication and convey the whole to the Publication Committee. The Publication Committee shall then scrutinize the communication with reference, first, to relevancy; second, to scientific value; third, to literary character, and, fourth, to cost of publication, including revision. For advice with reference to the relevancy, scientific value, and literary character of any communication the Publication Committee may refer it to a special committee of their own number or of the Society at large or may call to their aid from outside one or more experts. Questions of disagreement between the Editor and authors shall be referred to the Publication Committee and appeal may be taken to the Council.

12. Communications from non-fellows shall be published only by specific authority from the Council.

13. Communications from Fellows not presented at regular meetings of the Society shall be published only upon unanimous vote of the Publication Committee, except by specific authority from the Council.

14. Matter offered for publication becomes thereby the property of the Society, and shall not be published elsewhere prior to publication in the Bulletin, except by consent of the Publication Committee.

DETAILS OF THE BULLETIN

15. The matter of each memoir shall be classified by subjects, and the classification suitably indicated by subtitles; and a list of contents shall be arranged; and such memoir may, at the option of the Publication Committee, contain an alphabetical index, provided the author prepare and pay for it.

16. Proofs of text and illustrations shall be submitted to authors whenever practicable; but printing shall not be delayed by reason of absence or incapacity of authors more than one week beyond the time required for transmission by mail. Complete proofs of the proceedings of meetings shall be sent to the Secretary, and proofs of papers and abstracts contained therein and exceeding one-half page in length shall be sent also to authors.

17. The cost of proof corrections in excess of five per cent on the cost of printing may be charged to authors.

18. Unless the author of a memoir objects thereto, the discussion upon his communication shall be printed at the end thereof, with a suitable reference in the list of contents. In case the author objects to this arrangement, the discussion shall be printed in the closing number of the volume.

19. The author of each memoir occupying eight pages or more of text in the body of the Bulletin shall receive 30 "separates" without charge, and may order through the Editor any edition of exactly similar separates at an advance of ten per cent on the cost of paper, presswork and binding; and no author's separates of such memoirs shall be issued except in this regular form.

20. Authors of papers, abstracts, or discussions less than eight printed pages in length may order, through the Editor, at an advance of ten per cent on the cost of paper, presswork, binding and necessary composition, any number of extra copies, provided they bear the original pagination and a printed reference to the serial and volume from which they are extracted.

21. The Editor shall keep a record of all publications issued wholly or in part under the auspices of the Society, whether they be author's editions of memoirs, author's extracts from proceedings, or any other matter printed from type originally composed for the Bulletin.

DIRECTIONS TO PRINTER

22. Each memoir of the Bulletin shall begin, under its proper title, on an odd-numbered page bearing at its head the title of the serial, the volume number, the part number, the limiting pages, the plates, and the date of publication, together with a list of contents. Each memoir shall be accompanied by the illustrations pertaining to it, the plates numbered consecutively for the volume.

23. The author's separates of each memoir shall be enclosed in a cover bearing at the head of its title-page the title of the serial, the volume number, the limiting pages, and the numbers of the contained plates; in its upper-central part a title indicating the contents and authorship; in its lower-central part the seal of the Society; and at the bottom the imprint of the Society. (See also sections 19 and 20.)

24. The bottom of each signature and each initial page will bear a signature mark giving an abbreviated title of the serial, the volume, and the year; and every page (except volume title-page) shall be numbered, the initial and subtitle pages in parentheses at bottom.

25. The page-head titles shall be: on even-numbered pages, name of author and catch title of paper; on odd-numbered pages, catch title to contents of page.

26. The date of publication of each brochure shall be the day upon which the last form is locked and put on the press.

27. The type used in printing the Bulletin shall be as follows: For memoirs, body, long primer, 6-to-pica leads; extracts, brevier, 8-to-pica leads; footnotes, nonpareil, set solid; titles, long primer caps, with small caps for author's name; subtitles, long primer caps, small caps, italic, etcetera, as far as practicable; for designation of cuts, nonpareil caps and italics, and for legends, nonpareil, Roman, set solid; for lists of contents of brochures, brevier, 6-to-pica leads, a new line to an entry, running indentation; for volumes, the same, except 4-to-pica leads and names of authors in small caps; for indexes, nonpareil, set solid, double column, leaders, catch words in small caps, with spaces between initial letters. For serial titles, on initial pages, brevier block caps, with corresponding small caps for volume designation, etcetera; on covers, the same, except for page heads long primer caps; for serial designation, long primer; for brochure designation, pica caps; special title and author's name, etcetera, long primer and brevier caps; no frame on cover. No change in type shall be made to adjust matter to pages.

28. Volumes, plates, and cuts in text shall be numbered in Arabic; Roman numeration shall be used only in signature marks, and in paging the lists of contents, etcetera, arranged for binding at the beginning of the volume.

29. Imprimatur of Editor, on volume title-page; imprimatur of Council and Publication Committee, on obverse of volume title-page; imprimatur of Secretary, on initial pages and covers of brochures of proceedings. Printer's card, in fine type on obverse of title-page.

30. The paper shall be for body of volume, 70-pound toned paper, folding to 16 x 25 centimeters; for plates, good quality plate paper, smooth-surfaced, white, cut to 6½ x 10 inches for single plates; for covers smooth-surfaced, fine quality 70-pound light-buff manila paper.

31. The sheets of the brochures shall be stitched with thread; single page plates shall be stitched with the sheets of the brochure; folding plates may be either gummed or stitched (mounted on stubs if necessary); covers shall be gummed.

EDITION, DISTRIBUTION, AND PRICE

32. The regular edition shall be 660 copies in the regular quarterly form and 40 copies separately in covers of each memoir occupying eight pages or more of text. Each author of a memoir occupying not less than eight pages of text shall receive 30 copies of his memoir gratis. If two or more authors contribute

to a memoir brochure of eight pages or more in length, the edition shall be enlarged so as to give each author 30 copies. (By-Laws, chap. VI, 2.)

33. The undistributed residue of separates shall be held for sale.

34. The Bulletin shall be sent free to Fellows of the Society not in arrears for dues, and also to exchanging institutions. (By-Laws, chap. I, 3.)

35. The price of the Bulletin shall be as follows: To Fellows, libraries, and institutions, and to individuals not residing in North America, $7.50 per volume; to individuals residing in North America and who are not Fellows, $10. The price of each brochure shall be a multiple of five cents, and shall be, to Fellows, one cent per page plus three cents per plate, and to the public an advance of fifty per cent on the price to Fellows. The prices of the separate brochures and of the quarterly parts may be found in the front of each volume.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 30, PP. 143-164 MARCH 31, 1919
PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY

PROCEEDINGS OF THE TENTH ANNUAL MEETING OF THE PALEONTOLOGICAL SOCIETY, HELD AT BALTIMORE. MARYLAND, DECEMBER 28, 1918.

R. S. BASSLER, *Secretary*

CONTENTS

Session of Saturday, December 28

The tenth annual meeting of the Society was called to order by President Knowlton at 10 a. m., December 28, in the Civil Engineering Building, at Johns Hopkins University. The report of the Council was the first matter of business on the program.

Report of the Council

To the Paleontological Society, in tenth annual meeting assembled:

Two formal meetings of the Council have been held during the year—one at Pittsburgh, following the ninth annual meeting, and the second just before the present session. Several members of the Council have met informally at Washington during the year and discussed matters of business, which was concluded with the other Council members by correspondence. The following reports of officers give a résumé of the administration for the tenth year of the Society:

Secretary's Report

To the Council of the Paleontological Society:

Meetings.—The proceedings of the ninth annual meeting of the Society, held at Pittsburgh, Pennsylvania, December 31, 1917, and January 1 and 2, 1918, have been printed in volume 29, pages 119-166, of the

Bulletin of the Geological Society of America, published on March 31, 1918. In addition to the proceedings, five scientific articles, by members of the Society, were published in number 2, of volume 29, and other articles are contained in number 4 of the same Bulletin. In spite of the war conditions, the number of publications of the Society are therefore above the average.

The announcement that the tenth annual meeting would be held at Baltimore, in affiliation with the Geological Society of America, was delayed until late in the year, due to circumstances over which the Council had no control.

In March it was voted by the Council that in view of the increased membership and business of the Society and the increasing cost of service, a grant of $25 per annum should be made to the Treasurer for expenses in connection with his office.

Membership.—The Society has lost three of its charter members by death during the year—Prof. S. W. Williston, Prof. H. S. Williams, and Dr. Charles R. Eastman. We have also lost by death Prof. George W. Harper, well known educator and geologist, of Cincinnati, Ohio.

Nine new members were elected to the Society at the ninth annual meeting, and four of our members were elected to Fellowship in the Geological Society of America at the election just concluded. The result of the changes of the past year leaves the total membership at the end of 1918 as 189.

Pacific Coast Section.—Because of general conditions in the spring of 1918, it was found inadvisable to hold a meeting of the Pacific Coast Section for this year.

Respectfully submitted, R. S. Bassler,
Secretary.

Washington, D. C., *December* 26, 1918.

Treasurer's Report

To the Council of the Paleontological Society:

The Treasurer begs to submit the following report of the finances of the Society for the fiscal year ending December 13, 1918:

RECEIPTS

Cash on hand December 19, 1917	$639.37	
Membership fees (1916)	6.00	
Membership fees (1917)	12.00	
Membership fees (1918)	237.10	
Interest, Connecticut Savings Bank	18.97	
		$913.44

EXPENDITURES

Treasurer's office:			
Postage		$5.00	
Secretary's office:			
Secretary's allowance (1917)	$50.00		
Clerical help for 1916	25.00		
Clerical help for 1917	25.00		
Stationery and printing	63.74		
		163.74	
Geological Society of America:			
For printing separates		122.32	
			$291.06
Balance on hand December 13, 1918			$622.38
Net decrease in funds			$16.99
Outstanding dues (1917), 3		$9.00	
Outstanding dues (1918), 12		36.00	
			45.00

Respectfully submitted,

RICHARD S. LULL,
Treasurer.

NEW HAVEN, CONNECTICUT, *December* 13, 1918.

APPOINTMENT OF AUDITING COMMITTEE

The chairman then appointed H. F. Cleland and C. E. Resser as a committee to audit the Treasurer's accounts.

NEW BUSINESS

The following matters of business previously considered by the Council were then placed before the Society for action:

With the tragic death of Dr. Charles R. Eastman the Society lost its representative on the Supervisory Board of the American Year Book. On motion, Dr. W. K. Gregory was elected by the members to fill this vacancy.

During the year the Council was requested by the management of Botanical Abstracts to name two representatives on the permanent Board of Control of that organization—one to serve for four years and the second for two years. The Council nominated E. W. Berry for the four-year term and F. H. Knowlton for the two-year period; which action, on motion and vote, was approved by the members.

NECROLOGY

President Knowlton then reminded the members of the Society's loss during the year of four members, and called on Prof. Henry Fairfield Osborn first for an appreciation of the life of Prof. S. W. Williston. Professor Osborn's remarks are presented on pages 66 to 76 of this Bulletin. Professor Schuchert followed with a tribute to the life and work of Professor Williams, and Dr. John M. Clarke gave an account of Doctor Eastman's valuable contributions to science. The Secretary, as one of his former students, told the members of the great influence Prof. George W. Harper had on the younger paleontologists at Cincinnati, Ohio.

ELECTION OF OFFICERS

The results of the ballots for the election of officers for 1919 were then announced, as follows:

OFFICERS FOR 1919

President:

Robert T. Jackson, Peterborough, N. H.

First Vice-President:

Gilbert Van Ingen, Princeton, N. J.

Second Vice-President:

Walter Granger, New York City

Third Vice-President:

T. Wayland Vaughan, Washington, D. C.

Secretary:

R. S. Bassler, Washington, D. C.

Treasurer:

Richard S. Lull, New Haven, Conn.

Editor:

W. D. Matthew, New York City

PRESENTATION OF PAPERS ON PALEONTOLOGY

At 11 a m. President Knowlton called for the first paper of the session, which was presented and illustrated with sketches by the author. This

brought forth a spirited discussion, the essential features of which are reproduced below:

RELATION OF THE HOLOCHOANITES AND THE ORTHOCHOANITES TO THE PROTOCHOANITES AND THE SIGNIFICANCE OF THE BACTRITIDÆ

BY AMADEUS W. GRABAU

(*Abstract*)

The suborder Protochoanites was proposed by Grabau and Shimer, in 1910, for the reception of the Cambric genus Volborthella, which is characterized, among other features, by conical septa and a small siphuncle which is perfectly plain on the surface of the septa. It is considered ancestral, on the one hand, to the Holochoanites, and on the other to the Orthochoanites. By a crowding of the septa the endocones of the so-called siphuncle of the Holochoanites is produced, while a shallowing and separation of the septa produces the septa of the Orthochoanites. The septa chambers of the Holochoanites are a new feature. The endocones of the Holochoanites are considered the homologues of the septa of the Orthochoanites. On this view, the "siphuncle" of the Holochoanites is the homologue of the entire Orthoceran shell, while the endosiphuncle is the homologue of the Orthoceran siphuncle, and the endosipholining, when present, the homologue of the Orthoceran shell proper.

Bactrites is regarded as a lateral offshoot of the Orthochoanites, but not ancestral to any Ammonitean cephalopods, which are direct derivatives from Nautilian ancestors. The marginal siphuncle is a homœmorphic character and has no ancestral significance. The possibility that Bactrites is ancestral to the Belemnoidea is suggested by its similarity to the phragmocone of Atractites.

Discussion

The paper was discussed by Doctor Ulrich and Professors Schuchert, Clarke, and Osborn. Professor Schuchert stated that he had, so far, failed to find confirmation of the statement that the septa of Volborthella contains a median opening or siphuncle, although he had examined a number of specimens in the National Museum. A point also raised by Professors Schuchert and Clarke and Doctor Ulrich was regarding the validity of the homologies between the shell part of the Holochoanites and Orthochoanites suggested by the speaker. In reply, Professor Grabau reminded his hearers that it was not his intention to assert such homologies, but to reopen the question of the relationship of these older forms. In the first place, it did not seem probable that such highly specialized structures as the filling of the siphuncle of the Holochoanites should appear in ancestral forms, from which by subsequent reduction and the disappearance of these characters the less specialized siphuncle of Orthouras was produced. Moreover, the ontogeny of the older Holochoanites, such as Proterocameroceras, Nanno, etcetera, shows, according to the studies of Holm, Clarke, Hyatt, Ruedemann, and others, that the siphuncle appeared before the camerated part of the shell, Proterocameroceras, for example, having a very long preseptal stage. It is true that the filling of this preseptal stage by endocones is generally regarded as following the building of the first cameræ, but

there seems to be no valid evidence for such an assumption. If, as seems likely, some of the endocones are formed before the camerate condition appears, then we have a young shell characterized by an external wall at first, no doubt, conchiolinous, but later more or less calcified, and an internal series of more or less crowded conical partitions, the "endocones" penetrated by a median opening more or less slitlike, but subsequently modified, as shown by Ruedemann, into a central tube, the endosiphuncle. From this we are justified in arguing that the ancestors of these forms had essentially this structure, and this seems to be presented by Volborthella, so far as we know that form. Even should it prove that the septa of this form are without median opening (though the American material, poorly preserved as it is, seems to indicate such an opening), this would not seem to be a valid argument against the acceptance of Volborthella as ancestral—it would merely indicate that the siphuncular tube is a later development. When the cameræ first appear on one side, the original outer wall becomes divided, part continuing for a time as the endosipholining, which later ceases to develop, and part continuing as the external shell of the camerated portion. That the cameræ are a new feature seems to be clearly indicated by the ontogeny. They indicate a lateral contraction of the visceral sac and a complete cutting off of the space thus produced, whereas the septa of the Orthochoanites represent a withdrawal of the entire animal (except the siphonal tube) and a cutting off of the space by a transverse septum formed at the base of the visceral sac. They are essentially homologous to the new formed lateral cameræ in the living chamber of Ascoceras, the normal camerate portion of which is of the Orthoceran type except for the addition of collars in the ephebic portion. By acceleration in subsequent forms the marginal cameræ appear earlier and earlier until they appear before the endocones, and so more or less completely inclose the endoconic portion of the shell.

The derivation of the Orthoceran type of septuun and siphuncle from the Volborthella type, whether that has septal openings or not, seems a very simple matter. Future discoveries in the formations above the Cambric should show the steps in this modification.

Professor Schuchert agreed with the speaker that Bactrites represented an independent line of development, but doubted its ancestral relationship to the Belemnitidæ.

A second paper by the same author was also discussed in considerable detail by many of the members present.

INCLUSION OF THE PLEISTOCENIC PERIOD IN THE PSYCHOZOIC ERA

BY AMADEUS W. GRABAU

(*Abstract*)

The author has for many years restricted the term Cenozoic to the Tertiary and used Le Conte's term Psychozoic for the Pleistocenic and the Recent or Holocenic periods, thus making it equivalent to Quaternary in the broader sense. The justification for this appears in the now well established fact that man, the leading index fossil of the Psychozoic, appears in the middle and later Pleistocenic of Europe, while the Trinil race of Java appears to go back

to the beginning of Pleistocenic time. According to Professor Osborn and others, the Heidelberg race belonged to the second interglacial epoch, while in the third began the great cultural stages of Paleolithic man. There seems to be no justification for excluding the period of the "Men of the Old Stone Age" from the Psychozoic era, and the author proposes that in the future the following classification be adopted:

Psychozoic Era. (Quaternary Time.) Age of Man.
sens. lat.
Holocenic or Holocene Period.
Pleistocenic or Pleistocene Period.
Cenozoic Era. (Tertiary Time.) Age of Mammals.
Pliocenic or Pliocene Period.
Miocenic or Miocene Period.
Oligocenic or Oligocene Period.
Eocenic or Eocene Period.
Paleocenic or Paleocene Period.
Mesozoic Era. (Secondary Time.)
Usual subdivisions.

DISCUSSION

The paper was discussed by Doctors Osborn, Schuchert, Berry, Stanton, and others. There seemed to be a general disinclination to accept the term Psychozoic. Professors Schuchert and Osborn pointed out that a greater faunal break existed between the Pleistocene and the Holocene than between the former and the Pliocenic. Professor Osborn and Doctor Stanton, however, include both Pliocenic and Holocene under the Quaternary, and Professor Osborn argued for this twofold subdivision under the Cenozoic—that is, the Tertiary—as the Age of Mammals and the Quaternary as the Age of Man, while Professor Schuchert and others would prefer to discontinue the use of the terms Tertiary and Quaternary. Professor Grabau in reply restated his position that if it is recognized that Tertiary and Quaternary represented the two final divisions of the time scale, and if the latter, the Age of Man, is made to include both the Pleistocene and Recent (Holocenic), and, further, if it appears desirable to substitute terms equivalent to Mesozoic and Paleozoic for these numerical designations, then Cenozoic for the Tertiary and Psychozoic for the Quaternary would be the logical substitution.

Dr. John M. Clarke then delivered an address which had been prepared for the meeting at the request of the Council. The members followed his very interesting and timely remarks with close attention, and at the close of the paper Dr. J. C. Merriam expressed the appreciation of the Society.

PHILOSOPHICAL ASPECTS OF PALEONTOLOGY

BY JOHN M. CLARKE

Professor Osborn followed Doctor Clarke with two papers, in which he gave an account of the progress of work at the American Museum of

Natural History on the Sauropoda and other dinosaurs. In the first paper the work on the great monograph of Cope's Sauropoda was discussed and in the second an account of Cañon City genera, now supposed to be synonymous, was given. These two papers were discussed by Professors Schuchert and Merriam, with replies by Professor Osborn.

CHARACTERS AND RESTORATION OF COPE'S SAUROPODA

BY HENRY FAIRFIELD OSBORN

CAMARASAURUS AND AMPHICŒLIAS FROM CAÑON CITY

BY HENRY FAIRFIELD OSBORN AND CHARLES C. MOOK

Luncheon time having arrived, the Society adjourned until 2 p. m., when Vice-President Stephenson called the members to order for the presentation of the address of the retiring President.

CLIMATES OF THE PAST

PRESIDENTIAL ADDRESS BY F. H. KNOWLTON

(*Abstract*)

Doctor Knowlton's paper was divided into two parts, the first of which was devoted to the presentation of the evidence of fossil floras in their bearing in the interpretation of geologic climates. It now seems to be established beyond reasonable question that in the ages before the Pleistocene the climates were characterized by mildness, abundant moisture, equability, and non-zonal distribution. The second part of this paper was devoted to certain questions arising out of an attempt to explain non-zonal climates. During and subsequent to the Pleistocene ice-invasion climate has been under direct solar control. If the sun had dominated earth temperatures during all geologic time as it now does, it would be impossible to escape the conviction that climates should have been zonal in their distribution. It is possible to explain non-zonal climate in at least two ways—by heat derived from the earth itself, either as persistent earth heat perhaps augmented by radio-active heat, or by an affectively bigger sun. Certain astronomical objections seem to eliminate the latter factor, and attention is urged to a reconsideration of the first-mentioned factor.

President Knowlton then resumed the chair, and as a last matter of business for the session called for the report of the Auditing Committee.

REPORT OF THE AUDITING COMMITTEE

The committee announced that the Treasurer's accounts were found to be correct; whereupon it was voted by the Society that this report be accepted.

CONTINUATION OF PALEONTOLOGIC PAPERS

The first paper in the afternoon session was a study in evolution, which was presented by Doctor O'Connell and was discussed by Professor Osborn.

ORTHOGENETIC DEVELOPMENT OF THE COSTÆ IN THE PERISPHINCTINÆ

BY MARJORIE O'CONNELL

(*Abstract*)

The various interpretations which have been given to the term "Orthogenesis" are discussed and the distinction is drawn between the law and the explanation of orthogenesis. A statement will be made of the data available to the embryologist, zoologist, vertebrate and invertebrate paleontologist for orthogenetic studies, with particular reference to the possibilities for the observation of the facts of ortho-ontogeny and ortho-phylogeny.

As an illustration of the law of orthogenesis, the development of the costæ in a single species of Perisphinctes will be described. The bearing of the ontogenetic development on the phylogeny of Perisphinctes will be given.

An important contribution to the Mesozoic stratigraphy and paleontology of Cuba, illustrated by diagrams and lantern slides, was contained in the following paper presented by the junior author:

DISCOVERY OF THE OXFORDIAN IN WESTERN CUBA

BY BARNUM BROWN AND MARJORIE O'CONNELL

(*Abstract*)

The senior author, in the course of two trips to western Cuba, made collections from a compact nodular limestone, the Jurassic age of which was first pointed out by De La Torre, who discovered Perisphinctes in some of the nodules. No species have heretofore been described from the Jurassic of Cuba, but the horizon has been considered to be of the same age as the Idoceras beds of Mazapil, in Mexico—that is, Kimmeridgian. However, in working up the fauna, which consists mainly of ammonites, it was found that all of the species are closely related to or identical with forms in the Oxfordian of Durango, Mexico, which has been described by Burckhardt.

The general stratigraphic relations in Cuba will be discussed and the correlation with European and Mexican equivalents will be given, as well as a brief description of the new fauna.

The following paleontologic paper was then read by title:

A NEW EURYPTERID HORIZON

BY GEORGE HALCOTT CHADWICK

(*Abstract*)

Barge canal excavations near Pittsford, New York, have disclosed a new bed of *Eurypterus pittsfordensis* included in red Vernon shales, probably forty

feet above the old Pittsford black shale horizons. Casts of salt hopper crystals occur in the same slab, with nearly perfect exuvia, under which nestle dozens of Leperditiæ. The individuals are distributed profusely through a layer of dark gray shales twenty inches thick, inclosing a calcareous seam with *Emmelezoe decora*. *Ceratiocaris salina* also appears, but the chief zone of this is next beneath.

The indications are not favorable to a fresh-water habitat for this merostome.

In the absence of the author, the Secretary then presented the following paper, which on account of lack of time had to be given in abstract:

ECONOMIC VALUE OF PALEONTOLOGY

BY RALPH ARNOLD

PRESENTATION OF PAPERS ON STRATIGRAPHY

The reading of stratigraphic papers transferred to the Society's program from that of the Geological Society of America was then commenced. The first paper was presented by the author and was illustrated with charts.

AGE OF CERTAIN PLANT-BEARING BEDS AND ASSOCIATED MARINE FORMATIONS IN SOUTH AMERICA

BY EDWARD W. BERRY

(*Abstract*)

A discussion of the scattered occurrences of fossil plants in Colombia, Ecuador, Peru, and at various localities in Chile, together with the associated marine faunas. A correlation of these is made with the geological formations of the Panama Canal Zone and Graham Land. The results show a remarkably uniform sequence in the successive movements of the strand-line and a parallelism in the Mesozoic and Cenozoic history of the Pacific Coast region from the Isthmus of Panama southward to Antarctica.

The next two papers were presented by the senior author in each case and illustrated with numerous diagrams and sections. On account of the shortness of time still available, these two papers were combined. They were discussed by Messrs. David White and I. C. White.

TYPICAL SECTION OF THE ALLEGHENY FORMATION

BY CHARLES K. SWARTZ AND HARVEY BASSLER

(*Abstract*)

The importance of a clear understanding of typical sections of geological formations is fully recognized. The published descriptions of the typical sec-

tion of the Allegheny formation on the Allegheny River, of western Pennsylvania, present conflicting interpretations of the section, while adequate faunal and floral data are lacking for the correlation of these deposits with those farther east. The present paper is a contribution to a fuller knowledge of the typical section of the Allegheny formation in the vicinity of Freeport and Kittanning, Pennsylvania.

STRATIGRAPHY AND CORRELATION OF THE COAL MEASURES OF MARYLAND

BY CHARLES K. SWARTZ, W. A. PRICE, JR., AND HARVEY BASSLER

(*Abstract*)

The senior author is alone responsible for the discussion of the stratigraphy of the Coal Measures of Maryland. In the study of the correlation he has secured the cooperation of W. A. Price, Jr., who has investigated the marine faunas, and of Harvey Bassler, who has studied the Carboniferous floras. The conclusions presented are based on the concordant evidence afforded by the various lines of investigation.

The stratigraphic sequence of the Coal Measures of Maryland will be given the members, briefly characterized, and new limits will be assigned to certain of the formations. Attention will be called to a series of persistent and recognizable horizons in the Coal Measures of the northern Appalachians, which can be traced from Ohio eastward to Maryland and furnish a basis for the correlation of these beds throughout that area, including those of Maryland. The occurrence and significance of systematic changes in thickness of the sediments, the development of coal beds, and distribution of red beds will be discussed.

The following papers were read by title:

EOCENE DIVISIONS OF CALIFORNIA

BY BRUCE L. CLARK

(*Abstract*)

There are at least three distinct stratigraphic units in the Eocene of California. These, beginning with the lowest, are the Martinez, the Meganos, and the Tejon. The Meganos Group, the newly recognized division, is separated unconformably from both the Martinez Group and the Tejon Group and has a wide distribution throughout the State.

The fauna of the Meganos Group is very distinct from that of the Tejon and that of the Martinez. It appears to be of the same age as the fauna found in the Eocene sections at Marysville, Butte, and Table Mountain, near Oroville, California. A portion of the Eocene, described heretofore as the uppermost division, belongs in reality to the middle Eocene. The Ione, as recognized by them, is the equivalent of the Meganos Group.

Further details are presented as to the stratigraphic relationship of the Meganos and the Tejon of three sections in widely separated parts of the State.

SOME PROBLEMS OF THE ADIRONDACK PRECAMRIAN

BY HAROLD L. ALLING [1]

(*Abstract*)

During the detailed investigation of the Adirondack graphite deposits evidence was gathered that points to the following conclusions: That the Grenville series is extensively folded and severely metamorphosed; that the graphite schists furnish a basis on which a thousand feet of the series can be studied stratigraphically; that there is the probability of metagabbro masses that antedate the Laurentian granite. The Laurentian granite is present throughout the eastern and southeastern Adirondacks. There is evidence that there is another metagabbro that is later than the Laurentian granite, but older than the anorthosite-syenite-granite-gabbro series. Laccolithic bodies of the gabbro and diabase were seen. On the shore of Lake Champlain dikes of diabase, camptonite, and bostonite have such field relations that their relative ages can be determined.

PERMO-TRIASSIC OF NORTHWESTERN ARIZONA

BY HERVEY W. SHIMER

(*Abstract*)

Two months of field-work in Arizona, extending from Flagstaff, northwestward through the Painted Desert, over the Kaibab Plateau, and into the Torroweap Valley, resulted in many fossil collections from some fourteen, somewhat less accessible, localities. The collections here considered were made from the Kaibab limestone (Permian) and the Moencopie shales (Triassic).

STRATIGRAPHY AND STRUCTURE OF THE NEWARK SYSTEM IN MARYLAND AND ITS RELATION TO THE NEWARK SYSTEM OF EASTERN NORTH AMERICA

BY GEORGE EDWIN DORSEY [2]

(*Abstract*)

Studies made of the Newark System in Maryland and the immediately adjacent areas of Pennsylvania and Virginia during the spring, fall, and winter of 1917 and the spring of 1918 have led to new conclusions regarding the stratigraphy and structure of this problematical series of red beds. The Maryland areas of Newark rocks are critical, in that they afford very convincing evidence on fundamental and far-reaching conclusions as to the structure of the red rocks.

Three separate areas of Newark rocks are found in Maryland; a northern area, covering parts of Frederick and Carroll counties, the largest of the three areas; a central region—the smallest—extending as a narrow strip south from Frederick to the Potomac River, and a third southeastern area, lying almost wholly in southwestern Montgomery County.

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[1] Introduced by H. L. Fairchild.

[2] Introduced by E. W. Berry.

Although the field observations do not warrant an elaborate subdivision of the series, it is possible to recognize two very distinct types of lithology in the Maryland areas. The easternmost, which has been named the Taneytown facies, is composed of gray, pink, and red, highly arkosic sandstones, in places very micaceous. A coarse quartz conglomerate or a limestone conglomerate—the "Potomac Marble"—lies at the base of the series, the quartz conglomerate and the limestone conglomerate being generally mutually exclusive. The westernmost, named the Emmitsburg facies, is predominantly soft red to purple shale, weathering into cubes—in places micaceous.

Conspicuous mud-cracks, vertebrate tracks, fragments of wood, together with frequent cross-bedding, all point to continental conditions prevailing at the time of accumulation of the sediments. Several diabase dikes, with a general north-south direction, and one large sill, north of Emmitsburg, have been intruded into the series.

The structure of the red beds is a faulted monocline, with all dips northwest and west, toward Catoctin and South Mountains. At one spot in Maryland a superb exposure shows conclusively that reverse faulting has occurred, the west side showing relative upward movement. Once it can be proved that there has been reverse faulting, there is no evidence to limit the amount. It seems more rational, therefore, to assume an average thickness, say 5,000 feet, and ascribe the great east-west development as due to duplication. If such duplication has occurred, then the westernmost beds are not necessarily younger than the eastern beds, but rather eastern and western beds are of approximately the same age, differing only in character of sediments. Such is thought to be the case, and is the reason for speaking of the Taneytown and Emmitsburg facies rather than formations. It is also thought that the limestone conglomerate occurring at the western boundary of the Newark, and in New Jersey the heavy quartz conglomerate, are the same beds as those found to the east and are basal.

The red sandstones and shales are greatly jointed, in many places completely shattered to pieces. The strikes of the joints and faults are parallel, or nearly so; but since the faults are vertical and the joints are perpendicular to the bedding, duplication did not occur by slipping along joint planes.

The sequence of events which produced the Newark, as we have it today, is thought to have been as follows: Briefly, the Appalachian area at the close of Permian time was a region of crustal unrest—the forerunner of the later uplift. Situated on this area of unrest a region of depression developed, in which terrigenous red sediments slowly accumulated under true continental conditions. At a late period in this deposition continual depression caused a normal fault, which dropped the beds near their west side, causing the assumption of west dip.

At a subsequent time a radial thrust occurred, which was strongest in the mountains on the west, and died out eastward. As the direction of this fault-plane was parallel with the mountains, and also happened to be parallel with the strike of the Newark rocks which formed in a basin whose long axis was roughly parallel with the mountain axis, the vertical faults were strike-faults, the type necessary to cause duplication of the red beds. The dikes of diabase, where quarried, are vertical and are thought to have been intruded subsequent to duplication. The crescentic shape of the ends of the contemporaneous basalt sheets of New Jersey and Connecticut and of the intrusive sheets of Pennsyl-

vania, which are thought to have been intruded prior to duplication, are shown to furnish a most striking proof of the truth of the above theory.

REMARKABLE PERSISTENCE OF THIN HORIZONS

BY GEORGE HALCOTT CHADWICK

(*Abstract*)

A very unusual case of the persistence laterally for scores of miles of numerous intercalated thin beds of black shale and of limestone, often but half an inch and seldom over a foot thick, is afforded by the upper Devonian Hanover shale of Cattaraugus and Erie counties, New York. Several of these beds have been traced from Lake Erie to the Genesee River. Zones of small concretions in the green shale are equally persistent.

PORTAGE STRATIGRAPHY IN WESTERN NEW YORK

BY GEORGE HALCOTT CHADWICK

(*Abstract*)

Published correlations of the Lake Erie Upper Devonian with the Genesee standard column have been admittedly provisional, due to the difficulty of tracing formational units across a gap in the topographic mapping. During the past summer the writer had an unusual opportunity to complete this detailed tracing, with results notably different from those expected. The field relations of the published sections are found to be as follows:

Genesee River Section	*Lake Erie Section*
(Present, included in Chemung beds)	Portland beds Dunkirk black shale
Long Beards Riffs sandstones	(disconformity)
Wiscoy shales	Hanover shales
Nunda sandstones	(disconformity)
Gardeau beds	Angola shales
Grimes sandstone	(disconformity)
Hatch shales	Included in Rhinestreet
Rhinestreet black shale.	
Cashaqua green shale continuous to Lake Erie.	

For the name Portland, preoccupied and withdrawn, it is proposed to substitute Gowanda. These beds are terminated above unconformably by the Laona sandstone, which with two or three hundred feet of overlying strata appears to be cut out eastward by this unconformity, bringing beds apparently equivalent to the Girard shale of Pennsylvania down on the attenuated Gowanda near the Genesee River. It is thought this large overlap may furnish a more satisfactory plane of division between Senecan and Chautauquan.

STROMATOPORA GROWTH ON EDGE-ON CONGLOMERATE FROM THE SILURIAN

BY JOHN M. CLARKE

At 5.30 p. m. the Society adjourned.

On Friday evening, December 27, the members joined the Fellows of the Geological Society of America at a smoker at the Southern Hotel, while on Saturday evening members of both societies met at the annual dinner, which was also given at the same hotel.

Register of the Baltimore Meeting, 1918

H. M. Ami
Joseph Barrell
Harvey Bassler
R. S. Bassler
E. W. Berry
John P. Buwalda
John M. Clarke
H. F. Cleland
C. Wythe Cooke
A. F. Foerste
A. W. Grabau
C. A. Hartnagel
B. F. Howell
Edwin Kirk
F. H. Knowlton
J. C. Merriam
Marjorie O'Connell
Henry Fairfield Osborn
W. Armstrong Price
John B. Reeside, Jr.
Chas. E. Resser
Charles Schuchert
T. W. Stanton
L. W. Stephenson
Charles K. Swartz
E. O. Ulrich
Gilbert Van Ingen
T. Wayland Vaughan
David White

OFFICERS, CORRESPONDENTS, AND MEMBERS OF THE PALEONTOLOGICAL SOCIETY

OFFICERS FOR 1919

President:

Robert T. Jackson, Peterborough, N. H.

First Vice-President:

Gilbert Van Ingen, Princeton, N. J.

Second Vice-President:

Walter Granger, New York City

Third Vice-President:

T. Wayland Vaughan, Washington, D. C.

Secretary:

R. S. Bassler, Washington, D. C.

Treasurer:

Richard S. Lull, New Haven, Conn.

Editor:

W. D. Matthew, New York City

MEMBERSHIP, 1919

CORRESPONDENTS

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GEOLOGY IN THE WORLD WAR AND AFTER[1]

PRESIDENTIAL ADDRESS BY WHITMAN CROSS

(Delivered before the Geological Society December 31, 1918)

CONTENTS

INTRODUCTION

The great World War which has now come to a happy termination, through the triumph of the forces battling for justice and freedom over the powers of ruthless oppression, has been called "the war of the Age of the Natural Sciences." We all know how the wonderful discoveries and inventions of the last few decades in physics and chemistry have been applied to the development of terrible and often cruel weapons or engines of war. All sciences have been called on. Even geology has had its field, not so much through discoveries as from the waging of an almost new type of warfare, which became dominant at times in many places.

[1] Manuscript received by the Secretary of the Society June 2, 1919.

The magnitude and extent of the struggle made the mineral resources of the world a critical factor in many directions. We have been told at this meeting of the ways in which the training of the economic geologist has fitted him to promote the production of war minerals, or to show the relations of mineral resources to various phases of war administration.

It seems appropriate at the close of this meeting of the Geological Society to consider the ways in which the special knowledge of the geologist has been utilized at the battle front, much of it for the first time in the history of war. The opportunity to learn of this use of geology has come to me largely as the representative of the Society in the National Research Council, and hence it appears desirable to review the war-time work of the Division of Geology and Geography in the Research Council. A part of this address will be devoted to such a review.

Finally, it is important to consider the influence of war conditions on our science and to emphasize problems of the immediate future to which we must address ourselves.

War Geology

THE RÔLE OF GEOLOGY IN EARLIER WARS

War has developed from a contest of brute force and primitive weapons, between barbaric tribes, to a world conflict in which all the resources of science have been called into play by the specially trained minds of what we have perhaps mistakenly thought of as the most civilized nations. An aggressive war implies invasion of the enemies' country, and strategic control of campaign requires a choice of the avenues of attack, while a plan of defense implies resistance at the most favorable points.

The routes of approach and the positions for defense have been and must always be determined primarily by topographic and geographic conditions. The defenders have fortified the positions indicated by surface features as most favorable for blocking the advance of the intruder. Cities, harbors, and other important localities must be defended by fortifications within a limited space. Geology has, of course, entered into the selection of many positions for fortifications, whether this factor has been realized or not by those making the selections. To one understanding the physiographic development of a region, its recent geological history, the reasons for the noted strength of certain positions is clear.

It is impossible at this time to relate in detail the story of the use of geology in developing the science of fortification warfare from the time when precipitous walls, natural or artificial, made a fortress invincible, to the days of 1914, which witnessed the triumph of modern artillery and

explosives against supposed impregnable forts of Belgium. In general, the strength or vulnerability of a fortification depends in large degree on the nature of the rocks and their geological structure at and about the place fortified, in respect to the destructive effect of shell fire, the practicability of approach by tunnels or saps in mining operations, and the abundance and security of the water supply. That in any such case the military engineer and the geologist *should* work together for the best results is a thesis needing no defense before this Society.

In the Crimean War the Russians are credited with remarkable success in defending certain points, such as the Mast Bastion, near Sebastopol, because of their intimate knowledge and superior appreciation of the surrounding terrain. Austrian army officers have repeatedly called for geological surveys of the vicinity of Lemberg, Cracow, Pola, and other important points by well known geologists, such as Tietze, Stache, Waagen, and Vetters. A permanent and well protected water supply has been the main object of these studies.

In the Boer War a knowledge of the geological structure and water supply is said to have enabled the Boers to select strong defensive positions, while the British troops attacking them were placed at a marked disadvantage.

It is believed that the services of geologists have been utilized in practically all armies in the last few decades preceding the great war, in the limited field of the engineering problems of fortresses and of water supply for defensive positions. The organization of this special work was no doubt most highly developed in the German army, and of this I shall speak in some detail later.

The greatly increased application of geological knowledge in the present war has been due, first of all, to the development of position warfare. The contest between the Japanese and the Russians in Manchuria is said to have convinced some students of the subject that extended earthwork defenses or trenches possessed such strength when defended by modern arms and explosives that this might prove to be the dominant kind of warfare in future.

H. G. Wells, in "What is Coming?" gives a Pole named Bloch credit for the first clearly expressed appreciation of the coming importance of trench or position warfare, which was brought out in a book published shortly before the Boer War. Bloch thought that the increasing efficiency of defense by infantry, supported by artillery, along entrenched lines foreshadowed the end of wars between armies of nearly equal strength and equipment, because such contests must end in exhaustion and deadlock, and hence prove futile in the settlement of disputes.

The layman at least may be pardoned for thinking that Bloch's prophecy came near to fulfillment, as to the end of the Great War. Had the armies of all parts of the long line across Belgium and France and from Italy to the Baltic been fairly matched, a deadlock might have resulted, had not other major factors of decisive importance appeared in other fields. Perhaps future students of this war may point out that if Belgium and France had reinforced their great border fortresses by prepared trench lines, or if they had been ready to make them quickly on selected lines, the German army might have been stopped short, in 1914.

CONDITIONS AT THE BEGINNING OF THE WAR

It would seem that the Germans may have prepared in some measure for trench warfare, if it should come, for they dug in with amazing rapidity after the first battle of the Marne, on lines from which it took years to dislodge them. But they had planned a different kind of campaign, and it will be shown that their study of position warfare was far from thorough. This brings us to the question whether or not plans for the use of geologists in various armies had been made before the war broke out.

For all but the German army the events show that very slight preparation, if any, had been made for the use of such expert services. And even the German staff had no adequate plans for a geological corps. Our knowledge on this point is explicit.

More than one year before the declaration of war Captain Walter Kranz (retired) published in the Kriegstechnische Zeitschrift an article on military geology, in which he complains that while "in practically all fields of military life the sciences are pushing forward, and many of them have secured permanent posts in military service, only one branch of natural science must today stand aside as a stepchild, and that one is geology." Captain Kranz had served as an expert on the water supply and other engineering problems of fortresses, in which geology was important, but he had also given much thought to other services the geologist might render. His broad thesis is that the development of modern weapons has forced the soldier to adapt himself more carefully than ever in all his operations to the nature of the terrain about him and can no longer slight the science of that terrain—geology.

Captain Kranz reviews the need for a geologist's advice in connection with field fortifications, which, along the French front, would traverse a great section of formations of different character, from the crystalline rocks of the Vosges Mountains to the Eocene and Cretaceous near the channel, and taking part in structures the geologist alone would under-

stand. He also points out the desirability of preliminary studies, in time of peace, of the geological conditions about the possible enemies' strongholds. In general, Kranz foresaw much of the application of geology which has been made in the last four years.

The paper by Kranz provoked much discussion in Germany among geologists and military men, and after the outbreak of the war many articles appeared in newspapers and periodicals approving the plan of Kranz for greater geological service, suggesting new applications and revealing something of what was going on in developing that service, until, soon after the United States entered the war, the censor forbade further discussion, in the following terms:

"Publications which permit to be recognized the effectiveness of geology or kindred sciences in the service of the army are not permissible in the technical as well as in the daily press." Dated May 25, 1917.[2]

From these discussions it is clear that in the past only a very slight training in geology has been required for German army officers, and the demand is now made that at least certain selected officers be given a course in military geology covering several years.

Among the suggestions of valuable work to be performed by army geologists while the submarines were starving out England may be noted the exhortation to collect specimens for museums, when the advance is unfortunately delayed. Again, with a spirit worth remembering at this time. Professor Salomon, of Heidelberg, points out the great opportunity afforded by the thousands of miles of trenches to learn in detail "the geology of our neighbor's territories"—a knowledge so important for war work. "Yes, even if the next peace were an everlasting peace. But who ventures to hope that?" "Consequently we, whose territory has so often been the theater of invasion by our neighbors, must expect nothing else than to be obliged once more to draw the sword for the protection of our people. In such case it would be very easily possible that new battles must be fought over the very ground where our armies now stand. And our descendants would justly lament if we were now too short-sighted to make use of the happy opportunity to study the field of future renewed battle."

ORGANIZATION OF GEOLOGICAL WORK IN THE ALLIED AND GERMAN ARMIES

When the war broke out no one of the armies engaged possessed any organized geological service. The earlier battles were fought and the

[2] From New York Times.

general line of entrenched field positions from the channel to the Swiss frontier was established before any system of utilizing this line of expert assistance was provided. The discussion of this subject in German literature shows how the matter was taken up in that army. The organization of geological work in the British, French, Belgian, Italian, and American armies has not been publicly discussed, and I can make at this time only very general statements concerning them.

The German general staff recognized quickly that the position warfare into which they had been so unexpectedly forced required a development of geological service such as Captain Kranz had outlined the year before. From among the large number of professional geologists in the reserve and other branches of the army a few were first assigned to work on certain problems. Later the work was systematized and expanded, and it is known that at the end of the war each army possessed a corps of geologists of several ranks upon which calls could be made for expert advice. Perhaps 75 or 100 men were thus employed in the German armies on the western front. They were responsible only for advice and plans, not for execution.

In the British army a small advisory corps of geologists was early established, and it is interesting to note that it was under the leadership of the well-known Australian geologist, Prof. Edgeworth David, of Antarctic fame, professor at the University of Sydney, New South Wales, now commissioned as a major. He has been aided by Captain W. B. R. King, from the Geological Survey of Great Britain, and Lieutenant Loftus Hills, of the Geological Survey of Tasmania. The Mining Division of the British army includes a large number of men who have been trained in geology, but are professionally mining engineers.

The Belgian and French armies have apparently had no particularly organized geological force—a situation which it is difficult to understand, but which may be due, not improbably, to the early drafting of active geologists into the army for routine military duty and to ensuing heavy losses in the first terrible months of the war. The French and Belgian geological maps of the battle zone certainly contained information which must have been of much value to all the armies on this front.

The American Expeditionary Force has had the advantage of possessing in its Engineer Corps at general headquarters one of the most broadly trained American geologists, Alfred H. Brooks, of the Geological Survey, who was at first commissioned as a captain and at present holds the rank of lieutenant-colonel. Under his supervision there has developed a small force of geologists, all of whom were, I believe, transferred to this work from various other arms of the service. The first assistance to Major

Brooks came from Captain Lacroix, a mining engineer. More recently Captain Wallace Lee, Lieutenant R. S. Knappen, Lieutenant Crooks, Lieutenant Kirke Bryan, and possibly others, have been transferred to the geological service of which Lieutenant-Colonel Brooks is in charge, as chief geologist. It is known that had the war continued a short time longer several other well qualified geologists selected for this work would have been added to this special service.

We must wait for an authoritative statement from Colonel Brooks as to how the geological war service of our army has grown, what it has done, and how it has operated; but we may be sure that valuable work done by him individually, during his first year with the army, had much to do with this development, reinforced by the knowledge that our allies and enemies found it worth while.

I am not aware of any special development of geological service in the Italian army. For the various armies of the eastern front it seems probable, on several grounds, that no expert force of this kind has been formed. It has been recently announced, however, that our member, Major R. W. Brock, formerly of the Canadian Geological Survey, is chief geologist of the British army in Palestine.

GEOLOGICAL SERVICE ON THE WESTERN FRONT

It has been my privilege, in connection with work of the National Research Council, of which I shall presently speak, to learn something, primarily in a more or less confidential way, of the use made of geology in several of the principal armies engaged in this war. It is not fitting, even if time permitted, for me to enter into details of specific work accomplished, but we may hope that in due time a full discussion of the actual work done by geologists may be given by persons qualified by experience in the field to speak on that interesting topic. I will endeavor, however, to outline my understanding of the character of the war geologist's work, as it has developed in four years of fighting. A practically new field of engineering geology has developed during the war, and while we may hope that a need to cultivate this exact field may not appear again, the general engineering features of much of the war geologist's work are closely analogous to those of many civil engineering projects—a fact it is well to keep in mind for future consideration.

Let us start with the line of trenches along which the German army in 1914 stayed the counter attack of the Allies. It must be supposed that even the Germans did not utilize detailed geological knowledge of the terrain in locating or digging in on this line; but we know that this front has developed in the years into several parallel systems of trenches, com-

munication subways, galleries, dugout chambers for various purposes, all on a scale never before seen in warfare. Besides these excavations, there are the works of the Sanitary Corps for the establishment of a water supply, drainage, cess pits, disinfecting and germicidal plants; and in addition there are the roads and railroads, artillery emplacements, ammunition dumps, depots for supplies, etcetera, located near the front lines, the efficiency of which is distinctly influenced by the geological conditions.

We are familiar with the fact that these opposing systems of military works, extending for hundreds of miles, traverse a great variety of geological formations, ranging from the dune sands and marshes of Flanders to the crystalline rocks of the Vosges Mountains. They cross sections of Tertiary, Cretaceous, Jurassic, and Triassic sediments, including chalk, limestone, sandstone, shale, marl, clay, and various transition rocks, as well as valley and slope deposits of recent age. It is history that for three years and more this general line suffered many minor changes or readjustments—sometimes forced, sometimes voluntary.

Now no geologist or engineer who has dealt with problems involving rocks and imperfectly consolidated geological formations can fail to see how an experienced stratigraphic geologist and lithologist, accustomed to study similar formations in the field and to make, interpret, and use geological maps, could render great assistance to the military engineer in the development and improvement of this stupendous project; nor can *the thought be avoided that if one of the antagonists along this battle zone has possessed and used a superior knowledge of the local rocks and their distribution—that is, the geology—it has cost his opponent dearly. It is to be feared that the Germans have profited greatly in this use of the expert geologist.*

Let us now consider briefly the nature of the civil and military engineering problems involved in constructing, maintaining, defending, or attacking a great system of field fortifications such as has been described, which must traverse all the formations named. The work is largely excavation, of varying ease or difficulty, according to the rocks concerned. Under most conditions there is some opportunity for choice as to the site of the trench, subway, or dugout. A shifting of the trench line a few yards may greatly increase or decrease the difficulties of the task. The underlying rocks are often obscured by soil, weathering products, or vegetation, so that without geological data the conditions to be encountered below the surface can not be foreseen. The walls of trenches may give no suggestion as to the existence of rocks below in which needed dugouts or tunnels may be excavated with ease, while a knowledge of the stratigraphic section may show that favorable conditions are to be expected.

But the problems of the rocks themselves are simple compared with those connected with the presence of water in those rocks, circulating through certain strata, of ground water, or the rain and snow water of the surface. The water-bearing strata may furnish a desired supply for the troops or, when cut, may cause the flooding of extensive works. Again, the water-soaked trenches in impermeable clays may possibly be drained by boring or cutting into a porous permeable stratum. The depth of ground water level practically determines the feasibility, or the reverse, of securing dugouts in certain areas, and of mining and sapping operations. The knowledge of the ground water level and its seasonal variations is of great importance in many districts. I need not dwell on this.

The effect of surface water on the rocks forming the walls of this vast system of excavations is of critical importance, especially during the rainy season and in time of melting snows. Marly beds simply dissolve and the trench walls slump down. Other rocks require strong revetments or other supports; jointed shales and fractured rocks may slip as landslides into the trenches, and where drainage can not be effected a terrible condition of mire and filth soon arises.

The difficult problems arising from the combination of conditions so inadequately sketched are those with which the expert stratigrapher and hydrographic geologist are specially fitted to deal. By means of personal observation and by the interpretation of geological maps or reports, the geologist can reach an understanding of the situation more quickly than any other person. It is particularly in the avoidance of difficulties that his advice is of value. His ability to project or apply the information of a section of rocks obtained in one locality to surrounding or even to distant areas enables him to give advice bearing on plans of operation sufficient to save precious time, labor, and often the lives of men. Without such advice important parts of the defensive system may be much weaker than need be, perhaps to the degree that they must be abandoned even without attack by the enemy.

Up to this point only natural difficulties of making and maintaining this system of field-work have been considered; but each system is subject to the greatest damage, even to complete demolition, that an aggressive enemy can inflict. That there has been a considerable development of this type of the offensive we can not doubt, but details of what has been accomplished or suffered are as yet scanty, for evident reasons. We can be sure, however, that here, as in the construction of the works, the more complete the understanding of the geological conditions the better. It is a battle of wits, and the side possessing the more thorough understanding

of the enemies' weaknesses in the respects under consideration has a great advantage, which may well become decisive in certain areas.

Many accounts of conditions at the front give vivid descriptions of the fearfully destructive effect of modern explosives on the ground of the battle zone, especially of the terrific barrage fire from heavy guns. Such bombardment is undertaken at different times for different reasons. Its most destructive results in certain areas, arising from the local nature of the rocks, may be entirely aside from the main objective. But let us suppose that the geological experts of one army have made a special study of the enemies' position with regard to the rock formations, not only at the front, but for miles in the rear, including his communication lines and supporting works of all kinds, and that this special knowledge is used to direct destructive gun fire on points weakened as a result of a period of heavy rain. Can there be any doubt as to the superior effect of this fire over that from an equal bombardment at random?

The work of the geologist with the army has many phases not yet touched on which may be briefly reviewed. The process of mining is one of the oldest methods of attack on fortified positions. A knowledge of the rocks and ground to be encountered in a given project is manifestly of great importance. Ignorance of such conditions has been responsible for the total failure of many projects, even in this war; but perhaps the largest operation of this kind ever attempted in any war, namely, the destruction of the key position of Messines Ridge, was successfully planned by geologists of the British army.

The geological corps of an army engaged in position warfare is naturally called on for reports on many special subjects, with profile sections and maps in certain cases. These reports represent the adaptation of existing data to particular problems, such as maps of underground water resources and the distribution of formations specially classified on military grounds. This type of work may involve resurvey of some areas, as existing maps must in many cases prove inadequate in scale or accuracy.

The geologist can and does adapt the information of geological maps to a variety of special purposes; but the officer who can not read maps can not *use* them *efficiently* and very probably can not comprehend their importance.

One of the lines in which the geologist's advice is or should be sought is in regard to proper sites for camps, flying fields and hangars, artillery emplacements, ammunition dumps, and other storage places, communication lines, etcetera, the object being to decrease so far as possible the dangers and difficulties to which reference has been made.

The value for war purposes of a thorough study of a peculiar terrain

was well illustrated by Hindenburg's celebrated victory in the Mazurian Lake region of East Prussia, where 80,000 or 90,000 Russians are said to have been captured and thousands more killed or drowned in impassable swamps. An investigation and careful mapping of the Mazurian region, before the war, had revealed that certain swamps possessed a firm bottom and could be safely traversed by troops, while others of miry bottoms were quite impassable. It was further found that differences in the aquatic plants growing in the two types of swamps gave a reliable clue to the difference in the character of the bottoms. This knowledge permitted the Germans to drive the Russians into the impassable morasses, while their own army traversed other swamps with impunity.

This Russian disaster also serves to illustrate the necessity for an intelligent and alert appreciation on the part of the higher military authorities of the possible uses of scientific information of all kinds concerning a field of battle. The Germans themselves give the Russian scientists credit for initiating studies in agro-geology—the science of the distribution of plants with reference to geological conditions—in the swamp districts of Russia adjacent to the Mazurian Lake region.

When the complete story of the war services rendered by geology has been written, there will doubtless appear many instances in which highly technical knowledge has been required to solve obscure problems and where comprehension of the possibilities of such assistance was a prerequisite. Two such instances may be cited, both from the experience of the British army.

At one time it became very desirable to ascertain the source of materials used by the enemy in concrete work at a certain locality. After puzzling over this problem for a while a microscopical petrographer was called into consultation. His examination of thin sections permitted him to identify the material in question as volcanic rock of peculiar character, known to occur at an accessible locality in the enemies' territory.

In another place the troops at the front engaged in tunneling in certain formations were greatly afflicted by sores of special character. Three thousand to four thousand were incapacitated. The medical corps could not understand the prevalence of this trouble in restricted areas. Finally, the clay material of the tunnel walls was closely examined and found to act like fullers' earth in removing the natural greases from the skin, which thus dried and cracked, permitting ready infection under the conditions of trench life.

The lack of an intelligent understanding of the importance of geological conditions has certainly contributed to many military difficulties. For example: Within the territory of one of the countries opposed to the

Central Powers there is an area of great strategic importance, where the question of an adequate water supply for an army of occupation is of special moment. Before the war the Geological Institute of this country was requested to study the water-supply problem of this area with reference to military needs. It did so and submitted a report containing much valuable information. But when the army occupied the area in question, to defend it against invasion, the military commander, who could not appreciate the geological problem involved, did not make use of the report and, in consequence, his army suffered greatly from a lack of a proper and attainable water supply.

The Work of the Division of Geology and Geography in the National Research Council

HISTORY OF ITS ORGANIZATION

The National Research Council was organized by the National Academy of Sciences in the spring of 1916, at the request of President Wilson, to mobilize the scientific resources of the country in the interest of national security and welfare. Its duties pertained first to matters of defense, and later to assistance in the war. The early work of the Council was carried on through committees and subcommittees, among which were the Committee on Geology and Paleontology, of which J. M. Clarke was chairman, and that on Geography, under W. M. Davis. The work of these committees is well known to many of you.

The reorganization of the Research Council in January, 1918, intended to meet more efficiently the emergency conditions of the war period, provided for a few groups, called divisions, working from a central office in Washington. John C. Merriam was made chairman of the Division of Geology and Geography, the other members, at first, being: Whitman Cross (vice-chairman), F. W. De Wolf, Douglas W. Johnson, and Philip S. Smith. Owing to other important duties in the Council placed on Doctor Merriam, notably those of acting chairman of the Council for several months, I have been called on to act as chairman of the division for much of the time. It is at Doctor Merriam's suggestion that I assume to give at this time an account of the work of the division. It is practically a report to the senior national organization affiliated with the Council in the geological part of its work.

The controlling idea in selecting men for all divisions of the Council during the past year has been to bring in advisers who were closely connected with war activities. Doctor Johnson was commissioned in the Intelligence Service of the army early in the year and detailed for special

work in Europe. Attention to the geographical interests of the division was then provided for by adding to the Executive Committee Isaiah Bowman, of the American Geographical Society, and Captain Lawrence Martin, then of the Military Intelligence Branch and now a major on the general staff. J. E. Spurr, of the War Trade Board, was made a member of the division in April. Herbert E. Gregory was added in July, and you have heard at this meeting of the valuable special work performed by him. During a part of the summer Professor Gregory was acting chairman of the division.

The Executive Committee has held nearly thirty meetings during the year. It has been the practice to invite various geologists and geographers to attend meetings for conference on special subjects. Among those who have thus collaborated in the work of the division may be mentioned J. M. Clarke, W. M. Davis, E. B. Mathews, T. L. Watson, R. A. F. Penrose, Jr., C. P. Berkey, and W. W. Atwood.

GENERAL CHARACTER OF THE WORK

In speaking of the rôle played by geology in assisting the operations of the army at the front, it has been continually emphasized that the rendering of such assistance was difficult because there was at the beginning no adequate realization by military authorities that geological advice could be of much value. If such was the situation in France, how much more difficult must have been the task of geologists thousands of miles from the seat of war to secure opportunities for work with the army?

The geologist, as such, does not contribute, as does the physicist, chemist, or engineer, to the invention, development, or production of the munitions and weapons of war, or the machines and various agencies necessary to the equipment, transportation, and maintenance of an army. It is true that there has been a great field of activity for the economic geologist in promoting the production of the so-called "war minerals" essential in munitions and machines. With that part of the geologists' work the Research Council has naturally had little to do, the field being adequately covered by the Geological Survey, Bureau of Mines, the War Industries Board, and related Government or State organizations.

The importance of geographical information in military operations has long been appreciated to a much greater degree than that of geological knowledge; yet geographers have felt that the fundamental training in various branches of geography given in military schools of the day has been lamentably deficient. Not only has the instruction in map making, reading, and interpretation been inadequate to secure that familiarity necessary to proper use of maps, but the study of the main geographic

features of areas of possible future military operations has not been satisfactorily developed.

The work of the Division of Geology and Geography has been to promote by all practical and appropriate means the application of the experience and special knowledge of the geologists and geographers of the country to the problems of the war. Our particular line of effort has been in attempting to secure an adequate place for the earth sciences in the curriculum laid out for training the thousands of new officers for military duty. It has seemed evident that instruction to the vital significance of natural features of the battle terrain should accompany drill in many other directions.

Some details of the work of the division, mainly during the past year, will now be presented under appropriate heads:

ENDEAVOR TO PROMOTE THE USE OF GEOLOGISTS IN THE ARMY

The Geology Committee, early realizing that the advice of geologists should be available for our growing army at the front, presented a memorandum on the subject, with a recommendation to the Secretary of War, in May, 1917. This memorandum recited many lines in which geological information as to the battle terrain would be of value, referred to the known development of the German geological service, and offered the assistance of the Research Council. Some months later Secretary Baker replied that no increase in the geological service was contemplated at that time, but he suggested that a list of geologists eligible for such duty should be maintained. This was done.

Soon after the first troops of our expeditionary force were sent to France, Major Alfred H. Brooks was assigned to duty at general headquarters as geologist. We know little as yet of the conditions under which the geological service has developed, but it certainly was not rapid. The matter was constantly before the division, and as the hoped-for expansion of the geological work with the American Expeditionary Force did not take place, the subject was once more brought to the attention of army officers and of the Secretary of War in July, 1918, with a revised special statement of the German use of geologists. This was followed by complete translations, made by W. D. Matthew for the purpose, of many German articles on the applications of geology in war. An urgent recommendation was made to the War Department that the American army should be provided with a well organized and equipped force of trained field geologists. The cooperation of the division in securing a qualified personnel was offered.

At about the same time that this recommendation was made the value

of geological advice was more fully recognized by the general staff of the American Expeditionary Force, and the commissioning of several geologists and water-supply experts was requested by General Pershing. As the fighting came to an end, the scope of the geological work under Lieutenant-Colonel Brooks was being materially enlarged, as has been mentioned.

When the Division of Geology and Geography was organized, in January, 1918, there was much more information available as to geological work in the German army than in that of the United States or of any of the Allies. This was due to a study of German literature on the subject made by R. S. Knappen at the suggestion of Prof. C. P. Berkey. This material was generously placed at the disposal of the division. Fortunately Douglas W. Johnson, a member of the Executive Committee, was soon given a commission as major in the Intelligence Branch of the Army and sent abroad under conditions which allowed him, with official permission, to observe the use made of geology and geography in several of the allied armies and to report on the same to the Research Council. He was assisted in this work by Lieutenant S. H. Knight, a geologist, the Research Council meeting an appropriate part of the expense of this report.

The reports of Major Johnson are of great interest and value. He was able to observe the geological or geographical work in the armies of six countries at war with the Central Powers. Information of special value from some of these reports has been transmitted from time to time to appropriate branches of the army and on his return to this country a summary report was transmitted to the War Department on the observed applications of geology and geography.

It is a matter for regret that Major Johnson is not able to present a discussion of this subject to the Society at this meeting.

INSTRUCTION OF OFFICERS IN GEOLOGY, GEOGRAPHY, MAP-READING, ETCETERA

An effort to promote work of this kind in training camps was initiated by the Geology Committee in 1917, through its subcommittee on "Geology of Cantonments and Topographical Instruction in Training Camps," of which F. W. De Wolf was chairman, and has been continued by the division in the past year. The work originally planned by this subcommittee has progressed, though slowly. The U. S. Geological Survey has made topographic maps of the areas about several camps or cantonments and placed on the back of each sheet a description or "map story" intended to explain the significance of the topography from various stand-

points, and thus present practical lessons in map interpretation and reading. These texts have been in part arranged for in cooperation with the subcommittee.

Pamphlets on the geography, geology, etcetera, of several camps have been prepared, at the suggestion of the subcommittee, by State geological surveys. The following have been published:

The Country about Camp Lee, Virginia, by Albert W. Giles, Bulletin of the Geological Survey of Virginia.

The Environment of Camp Grant, by R. D. Salisbury and H. H. Barrows, Bulletin 39 of the Geological Survey of Illinois.

A Description of the Region about Camp Dodge, by James H. Lees, Bulletin of the Geological Survey of Iowa.

The Environment of Camp Funston, by Raymond C. Moore, Bulletin 4, Geological Survey of Kansas.

The matter of securing adequate instruction in officers' training camps in geology, geography, topography, map-reading, and kindred subjects was given a definite direction in the latter part of 1917 by the organization in the War Department of the Military Committee on Education and Special Training, with a board of civilian advisers, to which was given power to control all courses in training camps and schools. The introduction of new technical courses into an already crowded curriculum was a matter of practicability, controlled largely by the opinion of the military authorities as to the relative importance of such new instruction. So long as geology was slightly recognized at the front, the geological instruction of officers in training camps was hardly to be expected.

In June C. P. Berkey was made chairman of a special committee of the division to study once more the feasibility of introducing some instruction in geology and geography into officers' training courses, and, if found practicable, to formulate a plan for such work. After careful examination of the situation a report with recommendations was transmitted to Assistant Secretary of War Keppel. It was very favorably received and would doubtless have been acted on by the Military Committee had not the Students Army Training Corps plan matured at that time, making that course the natural place in which to concentrate efforts for the instruction in mind.

As chairman of the Research Council Committee on Relations with Educational Institutions, Dr. Merriam was early brought into conference with the Military Committee on Education and Special Training, and as the project for the Students Army Training Corps courses developed the Military Committee cordially welcomed suggestions from the Research Council in regard to all scientific courses. At this point H. E. Gregory

accepted a call to come to Washington and become chairman of a committee of the division to prepare outlines of Students Army Training Corps courses in military geology, geography, map-reading, and meteorology, for the consideration of the Military Committee. After many conferences with teachers of these subjects in colleges and universities, courses in these subjects were formulated and received the approval of the Military Committee. Unfortunately, through some misunderstanding, in the stress of issuing instructions by the Military Committee, the courses in these subjects we are considering were omitted from the curriculum first issued. This was subsequently corrected by supplemental instructions.

The evident need for text books in the courses in question was supplied under the direction of Professor Gregory, with the effective assistance of many collaborators, so that in a very short time volumes entitled: "Military Geology and Topography," "Introductory Meteorology," and a "Syllabus on the Geography of Europe" were prepared for publication. Their issue was delayed, through no fault of the committee or publisher, by strikes and ravages of the influenza epidemic. To Professor Gregory, as editor of this series of text books, great credit is due for both plan and execution.

Although the Students Army Training Corps has now been abandoned, the energy and interest put into the preparation of these text books and the courses in which they were to be used will surely not be wasted. This war of the sciences has placed some of them in a new light, and no science, perhaps least of all geology, will in future be regarded or taught entirely from the limited viewpoint of the past. These text books and recommended courses have ideas certain of development in years to come.

The interest of the Division of Geology and Geography did not end with the preparation of the text books. The need for maps and lantern slides in effective presentation of the Students Army Training Corps courses referred to and of several others was at once apparent. Maps especially were needed and requests for maps or information concerning them poured into the Military Committee, the Geological Survey, the National Research Council, and other agencies. The Division of Geology and Geography was instrumental in securing a conference of representatives from the Military Committee on Education and Special Training, the Military Intelligence Division (which could supply foreign maps), the Geological Survey (a source for domestic maps), the War Aims Committee, and the Research Council. As a result a committee under the chairmanship of P. S. Smith took up the matter, considered what maps were necessary, where they could be obtained and under what conditions they could be supplied, and made a report to the Military Committee just before the end of the war, and no action was taken. Professor Davis ren-

dered valuable assistance in recommending certain foreign maps for use in courses in physiography and map-reading.

Lantern slides to illustrate the Geography of Europe course were imperatively needed, and E. B. Mathews undertook, as a committee of one for the division, to find the best available material and arrange for its supply. He examined many collections of slides and sought for suitable photographs from which to make slides, but the task proved even more difficult than was expected, and before a satisfactory list of slides was made up the uncertainty as to the future of the Students Army Training Corps made further work inadvisable.

DISTRIBUTION OF BOOKS BY W. M. DAVIS AND D. W. JOHNSON

A reference to the now well known "Handbook of Northern France," by W. M. Davis, and the work "Topography and Strategy in the War," by Douglas W. Johnson, is appropriate at this place, because the principal object of the authors was to emphasize the importance of understanding the physiographic character of the terrain to officers in charge of military operations. The credit for these books belongs entirely to the authors, but the division has embraced every opportunity to recommend them and assist in their distribution among officers of the army. The enterprise and energy of Professor Davis secured, by private donation, a fund sufficient to publish and distribute several thousand copies of his handbook among officers in training camps and elsewhere. That this work has had a wide influence can not be doubted, since the author was requested by army authorities to prepare a similar handbook of western Germany.

The chapters of Johnson's book dealing with the western front contained such an excellent picture of the relations of strategy to topographic conditions, just where our soldiers were to battle, that Dr. Clarke arranged to have separate copies of these chapters, in pamphlet form, reprinted and gratuitously distributed among officers of training camps through the Military Intelligence Division. The American Library Association ordered several hundred more for use in its libraries at camps, in response to requests for the work. The greater part of the expense of printing these separates was borne by a member of the Geology Committee.

There is no doubt but that these books have contributed widely to that understanding among army officers of the relation of the topography and physiography of the terrain of battle to the conduct of military operations, which is a prerequisite to intelligent cooperation with trained specialists.

COOPERATION WITH GOVERNMENT BUREAUS AND OTHER ORGANIZATIONS

One of the principal functions of the National Research Council is to respond to requests from other organizations for assistance in securing in-

formation. The manifold character of this part of the division's work may be illustrated by examples.

a. The chairman of the division has been a member of the Joint Information Board of Minerals and Derivatives. This board of many connections was organized in March, 1918, as successor to the War Minerals Committee, which was a joint committee, with representatives from the Geological Survey, Bureau of Mines, the Institute of Mining Engineers, and the Geology Committee of the Research Council.

b. All divisions of the Research Council have supplied and received information of great importance to the army, navy, and other war organizations of our Government and of the Allies, through the medium of the Research Information Service, the headquarters of which is in the National Research Council, with branches in London, Paris, and Rome. I naturally can not go into details concerning the highly confidential and important work of this service. The Division of Geology and Geography has had a share in this work.

c. The division was instrumental in securing for the Fuel Administration a large amount of data concerning the fuel resources of various foreign countries.

d. The division has cooperated throughout the year in obtaining information useful to the military establishment of our country. The reports of Major Johnson to which reference has been made constitute a part of this work.

e. Reports on the manganese resources of California, resulting from work undertaken by the State Council of Defense, were transmitted to the Joint Information and the Geological Board through the division.

f. The division has cooperated with the Geological Survey in arranging for a study of the chromite and other war mineral resources of California, under the joint auspices of the Survey and the California State Council of Defense.

DISPOSITION AND USE OF THE REPORT ON MATERIALS AND FACILITIES FOR RAPID ROAD AND FORTIFICATION CONSTRUCTION

This report, planned and prepared by a subcommittee of the Geology and Paleontology Committee, under the energetic direction, first, of W. B. Clark and after his lamented death, of E. B. Mathews, was turned over in completed condition to the division on its organization. This important work, covering the coastal States from Maine to Texas, was planned before the United States entered the war and mainly as an aid to the army in anticipated projects of defense. It consisted of nine manuscript volumes and three atlases. A large number of men collaborated in its prep-

aration, including State geologists and highway engineers. In some States much original work in the field was necessary. The Chief of Engineers has recently expressed his high appreciation of the assistance officers of his corps have derived from consultation of the report. Special recognition has been given of assistance derived from this report in certain States. On the recommendation of Chairman Mathews a copy of this report has been deposited, for the present, with the United States Geological Survey, where it is open to representatives of any Government agencies desiring to consult it. Special use of the report has been made in connection with concrete work, particularly ship construction.

On a request referred to the division, an examination was made of the resources of the country in clear quartz crystals suitable for use in certain instruments. This work was undertaken for the division by G. P. Merrill. One phase of the investigation was a survey of and report on quartz occurrences of California by Austin F. Rogers. The expense of the entire investigation was met from the Research Council funds allotted to the division.

The important problems of the reconstruction of college and university courses in geology and geography after the war have been referred to the Geology and Geography Committees for study and report, with the recommendation that particular attention be paid to plans for securing: *a,* closer relations between the scientific and engineering courses; *b,* an adequate provision for pure research. It is evident that the lessons of the past four years contain much of great value in the development of courses of instruction in the sciences, while they also point to the necessity of increasing the research facilities of our universities and colleges.

The division has made a point of gathering data concerning geologists and geographers of the country, showing the special lines of work in which they are interested or engaged; their desire to enter into war work in the army or elsewhere; their fitness for possible field service and the positions occupied by those in service of any kind. The Census data obtained by the Geological Survey, the Research Council questionnaire for educational institutions, and that of the Committee on Geology and other information have been combined. These data have been used to some extent in making recommendations of men for certain work, but they have not been called on so much as was anticipated.

Geology after the War

It is an inevitable result of "the war of the age of the natural sciences" that the normal progress of those sciences through research and instruc-

tion has been greatly interfered with. Thousands of scientific men have left their laboratories and class-rooms to plunge with intense earnestness into war problems.

In many cases the specialist has been taken entirely out of the field of his science, which has thereby suffered a clear loss. In others the war problem has involved application of science to unusual ends with a gain to engineering or technology, and in a small number of instances the new work has been itself a research, with mutual benefit to the science and some particular application.

It is now time to survey the situation and see how much of good and how much of evil there is in it. We may be sure that in every experience in applying scientific knowledge to practical ends there is a benefit for science if we will but recognize and utilize it. On the other hand, there is great and manifest danger in a demoralization of the organized methods of progress in science.

The greatest benefit to science in general coming out of the recent war experiences lies in the fact that there has never before been a period in the history of the world when the truth of the proverb, "Knowledge is power," was so clearly demonstrated. The practical value of organized knowledge—that is, science—has been emphasized to every engineer, industrial leader, and Government executive who has real understanding. This greatly increased appreciation of the store of knowledge resulting from research should be of the highest importance in the future development of science.

Another and complementary source of profit from the war experiences of scientific men should be derived from the greater breadth of view they themselves must have henceforth as regards the relations of their professional work to the development of civilization. Many an investigator must have come to a better realization of the duty laid upon him to consider the bearings of his researches on the welfare of mankind.

The evils or dangers of the present situation are, however, perhaps more distinct and imminent than the benefits. It is to be feared that the recognition of the value of the scientific man's accomplishments will not go far enough, as a rule. Many specialists are sure to be wanted in technical positions, with a remuneration far beyond what they have received while engaged in teaching or in research. Will the industrial or executive agencies profiting by the training their scientific assistants have received in the field or laboratory realize the necessity of contributing a generous support to the prosecution of research in the abstract, that the store of new knowledge applicable to useful ends may continue to increase? Will it be recognized that the spirit of devotion to scientific

research is not only an inspiring and beautiful thing in itself, but is essential to real progress in science?

Let us turn now to the situation as regards the science of geology. For fifteen or twenty years past there has been an ever-increasing demand for geologists capable of applying the principles of their science to certain practical ends. On the one hand there has been a wonderful development of the mining industry and the value of the geologist's knowledge of ore deposits, or his familiarity with the structure of sedimentary rocks, essential in the discovery and exploitation of coal, oil, and gas resources, has been placed very high. On the other hand, the carrying out of the laudable policy of our Government to ascertain and conserve our natural mineral resources and to classify and utilize the public lands in an intelligent manner has also called for the services of many geologists. It is perhaps not unnatural that in connection with the development of this public work there has been expression, more or less clearly, of the idea that devotion to research for its own sake is perhaps a form of selfishness, as contrasted with the utilization of knowledge, which is laudable public service. It is to be feared that this view has been entertained both by Government officials and by many of the scientific men who have become enthusiastic over the new phases of their work. Such a conception fails to recognize the more fundamental truth that scientific research is itself a public service of the highest type.

The conditions of a world war have led to demands on geologists that they should apply their knowledge of certain basal factors to the solution of various problems of economics or political economy, far from their own proper field. Many of these studies have been of great importance and general interest. The results of some of them have occupied a prominent place in the program of our meeting this year. Under the circumstances, we welcome them; but it is clear that they are not geology. If geologists have been the best qualified experts to handle some of these questions, that fact is a commentary on the undeveloped condition of the science of economics, the system of governmental administration, and the plan of regulating international affairs. The value of some of these new or poorly developed lines of study is so manifest that their prosecution in future is surely to be anticipated. In the interest of all concerned it is desirable, however, to understand clearly that no new branches of geology have been discovered, but rather new applications of information more or less remotely of geological character. It is misleading to speak of "commercial geology," or to extend "economic geology" to cover all branches of economics which chance to deal with mineral products.

Geology, the science of the earth—its character, origin, and historical development, particularly as recorded in the rocks—has reached the point where the accentuated call for the application of the knowledge thus far acquired threatens to result in a serious decline in the prosecution of geological research. The science is still in the early stages of its development, and to retard its progress will be unfortunate in every way.

It is far beyond the possible limits of this address to analyze the present situation with desirable thoroughness and discuss in full the remedies for its unfavorable aspects. But some phases may be pointed out.

Professor Gregory has presented a picture of the recent decline in the attention paid to geology proper in our colleges and universities which calls for immediate attention. That this condition must be remedied is certainly not open to question, although the task is one of manifest difficulty.

Coincident with the decreasing interest in the foundation work of geology in educational institutions has come the great increase in the application of geology to practical ends in Government and State surveys and in technical work generally. This means an increase in technical courses, in mining schools, and heavy drafts on the personnel of geological departments in colleges. While such development is eminently desirable and must in the end redound to the advantage of the science, the immediate effect is unfortunate. As this call for the geologist to turn himself to economic work of some kind is accompanied by offers of relatively high remuneration and a cultivation of the insidious and erroneous idea of the higher public service thereby rendered, it is no wonder that for the time being progress in the science has been decidedly retarded.

The general character of the steps to be taken in restoring geology as a science to its proper place in schools, colleges, and universities, and in the research bureaus of the National and State governments is clear. In the first place, there must be serious and unrelaxing effort to educate the student of geology and all who are concerned in the technical use of geological knowledge to the appreciation of the fundamental truth that progress of the science itself is essential to advance in its application to practical ends. If this is true, then the position of the teacher and the research geologist must be more generously recognized and sustained than at present. The honorable and admirable attitude of devotion to science should not be made to mean too great a financial sacrifice.

The Geological Society of America is a body of specially trained men and women associated through their mutual interest in the science of geology. The Society is of much value to its members through the benefits derived from its annual meeting and its publication; but it does not

adequately function as a national force working for the general advancement of geology. The method of making the Society effective in this field is undoubtedly one requiring careful study and presents difficulties, but the obligation to find a way seems clear.

One direction in which the Society can be helpful at this time is through active cooperation with the National Research Council in its broad plan for stimulating both research and the application of science to the general welfare. The Society will have opportunity to influence the geological work of the Council by selecting several representatives in the Division of Geology and Geography. This connection should not be allowed to become an entirely nominal one, but should lead to a plan for active cooperation in carrying out the projects of the Council and in helpful suggestions as to its work.

In closing this address, I wish to express to the members of the Society my sincere thanks for the great honor which has been mine during the past year as President of this national organization. I look forward with confidence to the continued growth of the Society in lines which will promote the advancement of our special science and its usefulness to mankind.

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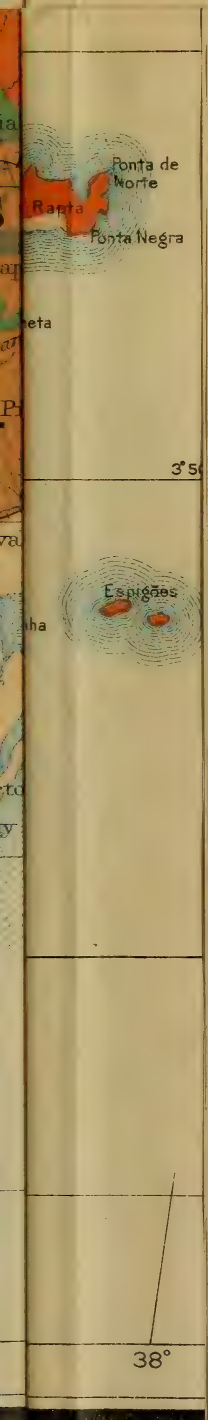
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38°

MAPPA GEOLOGICO
DO
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ORGANIZADO POR
JOHN CASPER BRANNER
PUBLISHED BY
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DEVONIANO
DEVONIAN
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SILURIAN
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EARLY PALEOZOIC
ARCHEOZOICO
ARCHEANO
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BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 30, PP. 189-338, PLS. 7 (COLORED MAP), 8-10 JUNE 30, 1919

OUTLINES OF THE GEOLOGY OF BRAZIL TO ACCOMPANY THE GEOLOGIC MAP OF BRAZIL[1]

BY JOHN CASPER BRANNER

(Presented by title before the Society December 28, 1917)

CONTENTS

[1] Revised manuscript received by the Secretary of the Society May 20, 1918.
This paper was presented to the Society under the title "Geologic Map of Brazil."

Foreword

The accumulation of the data for a geologic map of Brazil was begun by me in 1874, when I first went to that country, and has been kept up, as opportunities offered, down to the present time. The gathering and study of the material and the preparation of the map may therefore be said to represent the work of a considerable portion of a lifetime.

The data brought together on the map and in the accompanying text are published by the Geological Society of America primarily as a contribution to the world's knowledge of the geology of America; but, so far as I am concerned, it is meant especially to be of service to the Brazilian people, among whom I have spent many years, to whom I am strongly attached, and in whose welfare I am deeply interested.

It has been one of the greatest pleasures of my life that I have been able thus to contribute something to the knowledge of the geology of the country in which I began my professional career.

After a life spent chiefly in active geologic work and in the direction of such work, I should be remiss in my duty to Brazil if I did not use this occasion to urge on Brazilian statesmen the serious necessity for the active encouragement and support of scientific geologic work on the part of the national and state governments. Knowledge must precede the application of knowledge in geology as well as in other matters; and unless the development of the country's mineral resources be based on and proceed from a scientific knowledge of its geology, there must inevitably be waste of effort, loss of money, and the delay of national progress inseparable from haphazard methods.

The available Data

In general

Our knowledge of the geology of Brazil has hitherto been so fragmentary and uncertain that the generalized geologic maps thus far published have failed to furnish any clear conception of the geology of that country as a whole.

Many of the uncertainties, however, are not due to the lack of data, but rather to a lack of acquaintance with and coordination of data. By bringing together everything known and published on the geology of Brazil, and by seeking a rational interpretation of the available facts, it has been found possible to represent the general geology of the country fairly well. There are necessarily many and large areas about which little or nothing is known, and there are many questions about the ages and correlations of the rocks, their precise distribution, their structural details, and their mineral resources, that must go unanswered for the present or be answered only tentatively; but such doubts and uncertainties are inseparable from all progress in scientific work.

One who knows little or nothing of the difficulties of gathering geologic information in the field in Brazil may be disposed to place too low an estimate on the amount and character of the information shown on the map. But it should be kept in mind that the country is enormously big and, on the whole, but thinly populated; that vast areas therein are not yet penetrated by railways; that there are as yet but few good wagon roads in the country; and that the difficulties of travel and transportation in parts of the country remote from railways and navigation are not only serious, but sometimes almost insuperable.

Enormous areas of the country are also covered by dense and almost impenetrable forests, and of these trackless regions, some of them larger than the State of Pennsylvania, there are no maps whatever.

Of a necessity the gathering of geologic information under such circumstances is much more difficult than it is in a country like North America, where we have roads everywhere, railways never far away, and most of our forests open to persons on foot or even on horseback, to say nothing of the helpfulness of our excellent Land Office maps, even when there is nothing better available.

Furthermore, only two of the States, São Paulo and Minas Geraes, have attempted geological surveys, and there has been a federal survey only since 1907. With these important exceptions, there is, therefore, no bureau of the government to which geologists, engineers, or the public can turn for information about the geology of the country.

These facts, and others that need not be mentioned, have led me to value highly every bit of geologic information that has come to my knowledge, no matter how small it may be; indeed, much of the data has been gathered from individuals and from all kinds of publications, scattered far and wide, and many of them difficult or even impossible of access to most people.

But, as all human knowledge is imperfect and must, of a necessity, remain so, the best we can do is to push forward little by little the frontiers of our information, and, holding on firmly to such knowledge as we have, add to it as opportunity offers. It is only so that science makes progress in any country and in any field. In such spirit this map has been prepared, for the purpose of showing the state of our knowledge of the geology of Brazil and to prepare the way for additions to that knowledge.

The scale of the map makes it quite impossible to show many of the details that are known of the geology of some regions, while so little is known of other regions that the only safe thing to do is to leave the areas blank until our knowledge shall have been extended.

The geology shown on the map is based largely on personal observations covering a period of ten years of actual work and travel in all of the Brazilian States except Goyaz and Piauhy. Much aid has been received also from the unpublished notes of Roderic Crandall, who was some time my assistant and who did valuable work on the geology of Bahia, Minas, Ceará, Alagoas, Sergipe, and Amazonas. This direct information has been supplemented by all the data published and by much that is unpublished, but kindly furnished by friends and acquaintances who have a personal knowledge of the geology of certain parts of Brazil.

This statement is necessary because the map may otherwise seem to be more detailed than the published data seem to warrant.

Next after my personal observations and those of my assistants I have sought the original sources of all trustworthy information about the geology of Brazil—information scattered through books of travel and even through the daily newspapers of that country, as well as through the scientific publications of all parts of the world.

The observations of some of the early geologists have been made difficult by their use of certain terms. The word "itacolumite," for example, has been especially confusing, while the words "uebergangschiefer," traumatic shales, "formation phylladienne," and such like expressions keep one in constant doubt about the precise meaning of the authors using them.

The text accompanying the geologic map of Brazil is not intended to explain or give details regarding the geology, but simply to provide a brief condensation of what is known and to enable those who use the map, or who seek information about the geology of Brazil, to start with a fairly clear idea of what is known, and to obtain at first hand all of the published information that exists in regard to the geology of the country and of each state.

In view of the limitations of our knowledge, it is not possible to represent on the map more than thirteen subdivisions of the geologic column. In some localities many more subdivisions are known and over a limited area might have been shown, but there would be no particular object in giving all of these subdivisions on a map of this scale. The minor details, even where they are known, are necessarily omitted on account of the small scale of the map. In regions of horizontal rocks where partings are dendritic in form and outliers are abundant, these features can not conveniently be shown. The areas of old crystalline schists are almost everywhere traversed by dikes of eruptive rocks, but these dikes are usually too small to be shown on a map of the scale of this one. The same thing is true in the southern states, where numerous dikes cut all of the rocks below the Cretaceous.

Inasmuch as interest in the geology of Brazil is likely to be more or less a special interest in some particular branch, it seems worth while to refer to the available sources of information in regard to the different branches of geology, such as economic geology, paleontology, petrography, etcetera, and to other matter that geologists may need to know.

Many of the books and papers cited are not only not on geology, but they contain very little geological information; but the stray notes of a

traveler in little known regions often afford valuable clues, and sometimes they are the only ones we have.

MAPS

The maps of Brazil, like those of other countries, are not all good. There is no trustworthy large scale general map of the country. Some of the states have no surveys and are poorly provided with maps; others have lately undertaken good topographic maps, notably São Paulo and Minas Geraes. The São Paulo topographic maps are on a scale of 1 to 100,000, with 25 meters contour intervals, and five sheets have now been published. The topographic maps of Minas Geraes are on a scale of 1 to 100,000, with 50 meters contour intervals; ten sheets have been published. Of late years the need of trustworthy maps compelled the Inspectoria de Obras Contra as Seccas to make their own maps of several of the northern states in which drouths occur, notably in Piauhy, Ceará, Rio Grande do Norte, Parahyba, Pernambuco, Sergipe, and Bahia, and though made mostly by horseback meanders, are noteworthy as being the most valuable additions made of late years to the cartography of those states. This work was planned and carried out by the distinguished Brazilian geologist and engineer, Dr. Miguel Arrojado R. Lisboa, while he was director of the Inspectoria de Obras Contra as Seccas, and these maps have been our chief source of information in regard to the geographic details of the states so mapped.

In 1913 the Inspectoria Federal das Estradas, under the inspectorship of Dr. José Estacio de Lima Brandão, published a valuable modern atlas of the railways of Brazil; but the sheets are on various scales and are hardly available for the purposes of geologists. The atlas of Homen de Mello gives as good maps of the states as can be had on a small scale. The first edition of his work was published in 1882; the last in 1909. There are maps of most of the states, some of them remarkably good in view of the lack of trustworthy data for their construction.

The base map used for the geology has been compiled especially for the purpose by using all available data, in so far as it can be shown on a map of this scale. Dr. L. A. Bauer, Director of the Department of Terrestrial Magnetism of the Carnegie Institution, has kindly furnished me all the available determinations of latitude and longitude made under his direction in Brazil. I have also had the determinations made under Dr. H. Morize, director of the astronomical observatory at Rio de Janeiro, besides the results of the magnetic survey of eastern Brazil by Dr. Van Ryckevorsel and E. Engelenburg, published at Amsterdam in 1890.

Unfortunately it is impossible at present to tie into this network many

other places that should be or are shown on the map, and the location of geological data thus becomes very unsatisfactory in many instances. Notes under most of the states mention the authorities for the map of the state. Boundaries between the states are not yet definitely settled, and no importance can be attached to state boundaries given on the map. Only railways actually constructed are shown on the map. Flamsteed's projection is used as being the one best adapted to an equatorial region.

WORKS ON THE PHYSICAL GEOGRAPHY

Below are mentioned the principal works on the physical geography of Brazil:

Eschwege's sketch of the geology of Brazil, published in the Annales des Mines, volume VIII, 1823, is given in Portuguese at pages 35-39 of the appendices to Boubée's Geologia Elementar, Rio de Janeiro, 1846.

On the physical features of the country there is nothing better than the work of Elysée Reclus. His volume on Brazil has been translated into Portuguese by Dr. Ramiz Galvão, and many valuable corrections and notes have been added by the translator.

An older and less comprehensive work is Hartt's book on the Physical Geography and Geology of Brazil. It is primarily devoted to geology, but it brought together most of the data on the physical features of Brazil published up to 1870, when it appeared, and added Hartt's own observations along the coast from Rio de Janeiro to Bahia.

A much shorter paper by Derby is given in Wappaeus' "Geographia physica do Brazil," chapter V, pages 44-59, with a map. It appeared also in the Portuguese translation of Lapparent's Géologie, pages 333-343. This is in the Portuguese language. The same article was republished in English in The Rio News of December 5 and 15, Rio de Janeiro, 1884, and in the Annuaire géologique universel II, 2e parte, pages 29-35, Paris, 1886. The Revista Italo-Americana, volume I, Roma, 1902, contains a paper by Vincenzo Grossi entitled "Appunti sulla geografia fisica del Brasile." In The Brazilian Year Book for 1909, published at Rio de Janeiro, Mr. Derby's article on the physical and geological features of Brazil are given at pages 11 to 14.

A late interesting work that contains much valuable information is that of Dr. C. M. Delgado de Carvalho, entitled "Geographia do Brasil," 8°, 253 pages, Rio de Janeiro, 1913. There is a short but comprehensive article by the same author in the Scottish Geographical Magazine, February, 1918, volume XXXIV, pages 41-55.

Dr. M. A. R. Lisboa is preparing a comprehensive work on the physical

features of Brazil that will bring the subject up to date. I am unable to give the title of the work, however.

WORKS ON THE GENERAL GEOLOGY

There are but few books on the general geology of Brazil. Hartt's Geology and Physical Geography of Brazil, published at Boston in 1870, was the first considerable work treating of the geology of Brazil as a whole. The book is now long out of print, but copies are occasionally offered by dealers, and it can be found in most of our large libraries.

The article by H. Gorceix, in "Le Grande Encyclopédie," chapter IV of the second edition, Paris, 1889, is a short but good one on the general geology of Brazil.

In 1906 Branner's Geologia Elementar was published in Portuguese at Rio. This work was meant for a text-book for the use of Brazilian students, but the third part contained a résumé of the geology of Brazil. The second edition of this book was published in 1915, and the third part, on historical geology, gives brief statements of the distribution of rocks of different ages wherever they are known, and the footnotes refer to the authorities.

Rodolpho von Ihering, in his little book entitled "Landeskunde der Republik Brasilien," Leipzig, 1908, gives at pages 17-27 a sketch of the broad features of the geology of Brazil. It is a brief but good compilation from some of the best sources.

GEOLOGIC MAPS OF BRAZIL

Several attempts have been made to produce geologic maps of Brazil, but in most cases the maps have been on very small scales, and the geology has been represented by broad generalizations and necessarily based on very limited knowledge.

One of the difficulties any one encounters who undertakes such a map is the impossibility of correlating the geology of one area with that of another. This is difficult or quite impossible, even for those who do the field-work itself; but when one tries, from data gathered by two or more different geologists, to reconcile their differences of interpretation, and to correlate when the data for correlation are not available, it is clearly impossible to obtain results satisfactory to one's self or to others, especially if nice discriminations are attempted.

A. D'Orbigny, 1842.—The first geologic map of Brazil seems to have been one forming part of the "Carte de l'Amérique Méridionale indiquant ses differentes époques géologiques, par A. D'Orbigny," dated 1842 and published as plate X of "Voyage dans l'Amérique Méridionale, . . . par

M. Alcide D. D'Orbigny," tome III, 3e partie, Géologie, Paris, 1842. The map shows all of South America on a scale of 1 to 18,333,333. The geology is not shown in the usual way, but shaded areas represent the continent without geographic details subsequent to four geologic periods, namely, "apres les terrains siluriens," "apres les terrains carbonifères," "apres les terrains triassiques," and "apres les terrains crétaces." This chart, however, is a geologic diagram rather than a geologic map of South America.

Francisco Foetterle, 1854.—The next geologic map of Brazil of which I have any knowledge is that of Francisco Foetterle. It is entitled "Golpe de vista Geologico do Brazil, e de algumas outras partes centraes da America do Sul promptificado no Instituto Geologico Imperial Real Austriaco fundado e dirigido pelo Professor Guilherme Haidinger por Francisco Foetterle em Vienna em Avril 1854."

This map was made for Dr. K. Fr. Ph. von Martius, the Brazilian explorer, by Dr. Franz Foetterle, who was at the time an assistant on the K. K. geologischen Reichsanstalt. I had the good fortune to see the original of this map at the rooms of the Geological Society of London in 1904. The author had made himself familiar with most of the data published up to that time on the geology of Brazil and of the adjacent regions. Altogether it is a remarkable map, evidently made by a discriminating and painstaking person. In the title itself are given the names of the authorities consulted, and, besides the geology, there are many marginal notes on elevations and historic data of interest. The geology is shown entirely across the South American continent, from 5 degrees north latitude to 35 degrees south latitude.

The scale is 1 to 15,000,000 and the geologic coloring shows the following divisions: five divisions for granites, gneiss, itacolumite, and schists (chloritic and traumatic); Silurian, Devonian, amphibolite, limestone, Carboniferous, Trias, marl, red sandstone, volcanics, Tertiary, diluvium (pampas), and special signs for gold, diamonds, iron, and coal.

In the light of our present knowledge of the geology of Brazil, Foetterle's map must be regarded as having but little more than a historical value.

Franz Foetterle, 1856.—In Petermann's Mittheilungen, Gotha, 1856, Franz Foetterle has an article at pages 187-192, on "Die Geologie von Süd-Amerika," which is accompanied by a geological map of the entire continent of South America on a scale of 1 to 25,000,000. In so far as Brazil is concerned, it is a repetition of his map of 1854. On this smaller one he shows fourteen geologic divisions.

J. E. Wappaeus, 1884.—"A geographia physica do Brasil" (Edição condensada), Rio de Janeiro, 1884. This work contains a chapter by Orville A. Derby on the structural geology and minerals of Brazil. The text forms chapter V, pages 44 to 59, and it is accompanied by a sketch-map made by Derby showing the geology of Brazil. The scale is very small (about 1 to 90 millions) and the geological column is shown in six divisions, namely: Archean, Paleozoic, Carboniferous, Trias (?), Cretaceous, and Tertiary and Quaternary (combined). No attempt is made, however, to show these subdivisions over more than about half of the area of Brazil. The text accompanying this map is based partly on Derby's personal knowledge, but no references are made to the other sources of information used in the preparation of the map.

Dr. Hermann Berghaus, 1892.—"Atlas der Geologie" (Berghaus' Physikalischer Atlas, Abteilung I), Gotha, Justus Perthes, 1892. Plate number 14 shows the geology of the whole of South America; it seems to have been compiled chiefly by Dr. G. Steinmann. It is on a scale of 1 to 30 millions. There are eleven subdivisions of the geologic column, as follows: (1) Archean, (2) younger eruptives, (3) crystalline schists, (4) Paleozoic, (5) coal beds with Glossopteris flora, (6) Jura and Trias (not in Brazil), (7) Mesozoic, (8) Cretaceous (?), (9) basic eruptives, (10) Tertiary, (11) Quaternary.

Domicio da Gama, no date.—In his "Atlas universal de geographia physica e politica, nova edição correcta, por Domicio da Gama, Rio de Janeiro," no date, the author gives on plate 32 a geologic map of Brazil. This map has not been seen by the present writer.

Barão Homem de Mello e Dr. Francisco Homem de Mello, 1909.—"Atlas do Brazil," Rio de Janeiro, 1909. A plate entitled "Esboço da carta geologica do Brazil," on a scale of 1 to 19 millions, represents the general geology of Brazil. There are only four colors used for the geology, as follows: Archean and Lower Paleozoic, Middle and Upper Paleozoic, Mesozoic, and a single color for both Tertiary and Quaternary. No author's name is given on the plate, nor does the text make any mention of the name of the person responsible for the geology shown, but Barão Homem de Mello informs me that it was prepared for him by O. A. Derby. The fact that no authority is mentioned on the map is probably because Mr. Derby was very cautious about committing himself to the generalizations required for a map of the kind; and no one knew better than he did the limitations of our knowledge of the geology of Brazil.

Manoel Paulino Cavalcanti, 1910.—A series of maps of Brazil showing climate, agriculture, statistics, and geology was published at Rio de Janeiro in 1910 by the Sociedade Nacional de Agricultura under the

editorship of Dr. Manoel Paulino Cavalcanti, director of the Posto Zootechnico Federal. It is on a scale of 1 to 12 millions. Eight subdivisions of the geologic column are shown, namely: Quaternary, Tertiary, Cretaceous, Trias, Carboniferous, Devonian, Silurian, and Archean. Though this map is largely diagrammatic, it is the most dependable effort thus far made to produce a geologic map of Brazil.

Theodoro Sampaio, 1911.—In his "Atlas dos Estados Unidos do Brazil pelo Engenheiro Civil Theodoro Sampaio," published at Bahia in 1911, the author of that work gives a small geological map of Brazil on a scale of 1 to 40 millions. Six geologic divisions are shown. In spite of the very small scale, it is among the best geologic maps of that country.

Miscellaneous reproductions.—Several small maps have been published showing the general geology of Brazil, but they have evidently been made from some of the larger maps already mentioned. One that may be taken as an example is that given by Prof. James Geikie in his paper, "The evolution of climate," published in The Scottish Geographical Magazine, volume VI, pages 57-77, Edinburgh, 1890, and accompanied by small scale maps of the geology of the globe. The title of the map, however, says that it is "after Berghaus, Marcou, and other authorities."

Another geological map of South America on a scale of 1 to 50 millions is given opposite page 57, in "Süd und Mittelamerika von Wilhelm Sievers, Leipzig und Wien, 1903." The title of this map says it is after Berghaus and others.

In addition to these maps of the whole country, a few geologic maps of some of the states or provinces have been published; these state maps will be mentioned in the bibliographic reference to the states themselves.

Outlines of the stratigraphic Geology

In general

The text on the stratigraphy is intended to give only a brief outline of the general geology of Brazil, including statements of the character of the rocks, structural features, areal distribution, and the subdivisions of the geologic column—enough, it is hoped, to guide geologists, and to serve as a basis for future work.

If more details are required they may be found (in case they are known and published) in Branner's Geologia Elementar, second edition, or in the papers cited in the bibliographies of the different states.

In the course of the preparation of the map many problems regarding stratigraphy have demanded attention, and they had to be dealt with in order that the work might go forward.

It has not been my purpose, however, to settle controverted questions in Brazilian geology further than the facts warrant or further than was necessary in order to put the geology on the map in one way or another. I have frankly stated doubts wherever they exist, and I ask the indulgence of those who may reach different conclusions in regard to the many disputed problems. It is hoped that even the statement of doubts and differences of opinion may help toward their settlement by leading to the accumulation of evidence in the field. The field geologist must therefore feel at liberty to look on the solutions here suggested as working hypotheses, to be confirmed if found correct, or to be rejected if found wrong.

In regard to the areas left blank on the map, there is no information available at present.

ARCHEAN

General discussion.—The rocks referred to the Archean in Brazil are granites, gneisses, quartzites, marbles, and crystalline schists. Too little is known of these old rocks at present to warrant such a separation of them as has been made of similar rocks in North America; for that reason they are called the Brazilian complex. Many years ago it was believed that *Eozoon canadense,* a supposed fossil foraminifer supposed to be characteristic of the Laurentian, had been found in the Brazilian Archean near the falls of Paulo Affonso, in the State of Alagoas. Derby said of it: "Esta descoberta confirma a opinião emittida pelo fallecido Professor Hartt sobre a idade geologica dos gneiss brazileiro." [2] The supposed fossil, however, is not now regarded as a fossil at all, and no further attempt to subdivide the Archean of Brazil has been made or can be made as yet. Rocks of the Brazilian complex are found in all of the states, and the area in which they are the surface rocks in Brazil is large, and much of it not yet outlined, while the structure and character of the rocks vary greatly. About Rio de Janeiro and through the Serra do Mar generally they are mostly massive granites and gneisses. In northern Brazil they are more closely folded; everywhere they are faulted and cut by pegmatite and other dike rocks and traversed by veins of quartz.

But little is known of the structure of the Brazilian complex. Much information on the subject is scattered through the literature, but widely separated areas can not be confidently tied together with the data now available. Even the "chief lines of elevation or folding" suggested by

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[2] O. A. Derby: Reconhecimento geologico do Valle do São Francisco, p. 11. Rio de Janeiro, 1881.

Dr. John W. Evans[3] are not supported, so far as Brazil is concerned, by our knowledge of the local details.

Over much of the Archean area are scattered infaulted remnants of old Paleozoic rocks that yield a peculiar and characteristic topography. The infaulted masses are of all sizes, from areas of thousands of square kilometers down to only a few square meters. These rocks, however, belong with the next newer series, where they are spoken of more at length.

Economic geology of the Archean.—Our imperfect knowledge of the stratigraphic limits of the Archean rocks of Brazil makes it difficult to know precisely what rocks and minerals are to be credited to that division of the geologic column. Furthermore, minerals that probably originated in newer rocks are now often found in the Archean areas, where they have been left by the denudation of later series to which they properly belong. On the other hand, the Archean rocks are the original sources of certain minerals that are now found in later deposits in which they have been concentrated, as, for example, the monazite sands of the coasts. It can confidently be stated that the Archean rocks of Brazil contain many minerals which have not yet been developed economically in that country. The entire list includes gold, copper, platinum, tungsten, mica, marble, talc, apatite, graphite, potash-bearing rocks, precious stones, and excellent building stones. This list, however, is not complete.

EARLY PALEOZOIC

General observations.—The separation of the rocks of the Brazilian complex from the next newer series can not be made with confidence at present, but for purposes of discussion the top of the Archean is placed at the base of the quartzite called "itacolumite," in Minas.

The groups of rocks here called early Paleozoic can not be clearly defined for lack of stratigraphic data. No fossils have been found in any of them. Many of them have been profoundly metamorphosed; others have been much less affected; over vast areas they have been almost completely removed by denuding agencies, but over these same areas remnants of the old Paleozoic sediments stand out in bold relief as isolated knobs, peaks, and even as bold and rugged mountain ranges. The rocks vary from soft clay shales to the hardest of quartzites, the quartzites invariably forming the ridges, while in the parallel shale beds intervening valleys have been cut. Within limited areas the structural features are sometimes remarkably uniform, though not perfectly so. The structure shows that these early Paleozoic sediments have been extensively dislocated by thrust-faults and one end of the beds thrust down into the underlying

[3] Quart. Jour. Geol. Soc., vol. lxii, p. 90. London, 1906.

gneisses and granites. The result is a section somewhat like the ones here shown, but varying according to the angle of the fault-plane, the amount of the thrust, etcetera. These early Paleozoic beds are thus brought into intimate relations with the Archean rocks, and it seems quite probable that the high metamorphism and the presence of so many characteristic and valuable minerals may be due, in part at least, to these relations. The dips of the beds are generally high, and not infrequently the beds are nearly or quite vertical. The statement is sometimes made that the dip is always toward the east,[4] with a rugged outcrop on the west;

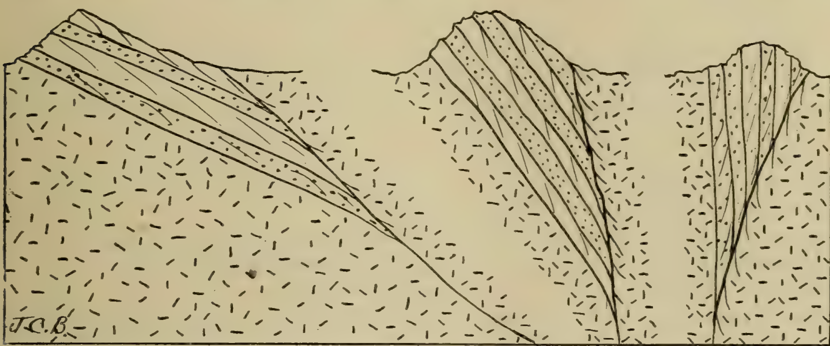

FIGURE 1.—*Theoretic Structure of Thrust-faulting of early Paleozoic into the Archean*

this is locally, and only locally, true. In the State of Bahia the Serra de Jacobina, which belongs to this series, dips about 60 degrees toward the east (with slight variations) along its entire length—a distance of 225 kilometers.

In the State of Minas Geraes, where the early Paleozoic beds have been most studied and written about, the direction and angle of the dip varies much, and the sequence of the beds is variously stated by different writers.

I have here brought together the sequence in Minas Geraes as given by eight different geologists:

ESCHWEGE, 1831	CLAUSSEN, 1841
(Gebirgskunde Brasiliens)	(Acad. Roy. Bruxelles, volume VIII)
Uebergangsthonschiefer	Terrain transition
Eisenglimmer	Traumateux
Itacolumite-quartz	Itacolumite
Urthonschiefer	Micacique
Kornquartz	Quartzitique
Granite-gneiss	Granite-gneiss

[4] Heusser u. Claraz: Zeit. Deut. Geol. Gesell., vol. xi, p. 451. Berlin, 1889.

HELMREICHEN,[5] 1846 (Geog. Vorkommen der Diamanten, 1846)	GERBER, 1863 (Noções . . . da Provincia de Minas Geraes, 1863, pages 17-20)
Graywacke	Transition
Itacolumite Talcose and clay slate Slaty gneiss	Itacolumite Iron, talc, and steatite Itabirite Quartzite
Granite-gneiss	Granite-gneiss

GORCEIX, 1881 (Ann. Escola de Minas, volume I)	FRANCISCO DE P. OLIVEIRA, 1881 (Ann. Escola de Minas, volume I, page 53)
Paleozoic limestone	Limestones, shales, and red sandstones
Schists Iron (itabirites) Quartzites (Caraça) Schistose quartzite	Itabirites Talcites and phyllites Quartzites Talcose rocks
Granite-gneiss	Talcites-mica schists Granite-gneiss

GONZAGA DE CAMPOS, 1910 (Iron Ore Resources of the World, volume II, page 816)	HARDER AND CHAMBERLIN, 1911 Journal of Geology, volume XXIII, pages 345-347)
	Limestones, age?
Iron ore (itabirites) — Sedimentaries	Itacolumite quartzite Piracicaba formation Iron (mostly itabirite) Batatal schists Caraça quartzite
Crystalline schists and granite	Granite, gneiss, schists

These tables lead to the conclusion that either the various writers on the early Paleozoic rocks of Brazil are not speaking of the same places or else they disagree about the subdivisions of the series. My own observations, both on the rocks themselves and on the writings of these geologists, lead me to believe that the rocks of this series vary from place to

5 Helmreichen's section is at Grão Mogol and it probably does not belong here.

place just as other sedimentary series do, and that the disagreements of geologists are due to their efforts to generalize from their observations. The scientific and economic importance of this series of rocks in Brazil entitles it to the careful attention of geologists.

Economic geology of the early Paleozoic.—Economically, the early Paleozoic rocks of Brazil are of the greatest importance, for they include not only the gold veins from which existing rock mines obtain their gold, but they are the indirect sources of the gold obtained from the old placer washings. This series also includes the great iron and manganese deposits of Brazil. The diamonds and other precious stones of Brazil are also supposed by some geologists to have originated in these early Paleozoic beds, though there is difference of opinion on this subject. Without going into details, it is evident that this series of rocks is of the greatest economic importance and of the highest scientific interest.

SILURIAN

The oldest known fossils found in Brazil are from the Silurian, in the States of Amazonas and Pará. (See Clarke and Katzer under those states.)

The Silurian rocks, where they are recognized as such, are marine sediments, mostly in the form of thin-bedded sandstones. They are exposed where crossed by the Trombetas, Curuá, and Maecuru rivers on the north side of the Amazon River, and dip gently southward. On the Trombetas the zone is from six to eight kilometers wide. The fossils show them to be equivalent to the Niagara beds of New York State. Although the rocks that overlie the Silurian north of the Amazon appear again on the south side of that stream, no rocks known, from paleontologic evidence, to be Silurian appear immediately south of the Amazon.[6]

It is highly probable that there are rocks of Silurian age in many other places in Brazil, notably in Bahia and Minas,[7] but the absence of fossils has thus far prevented their confident identification.[8]

DEVONIAN

General observations.—The Devonian is found in the States of Amazonas and Pará in the north, in São Paulo and Paraná in the south, and in Matto Grosso in the west. For the fossils found in the Brazilian De-

[6] F. Katzer: Geologie von unteren Amazonas Gebietes, p. 216.

[7] See Branner: Am. Jour. Sci., vol. xxx, November, 1910, p. 343, and vol. xxxi, June, 1911, p. 481.

[8] On the Rio São Francisco, at Bom Jesus da Lapa, State of Bahia, are limestones in which fossil corals (Favosites and Chetetes) are said to be found. Derby believed them to be Silurian, but both forms may well be Carboniferous.

vonian, see the titles under those States by Clarke, Katzer, Kayser, Oliveira (Euzebio de Paulo), Rathbun, Schuchert, Smith, Vogel, and Von Ammon.

In the Amazon region the Devonian rocks are white and yellowish sandstones and black and reddish shales. Along the north side of the Amazon they are exposed from just north of Almeirim westward to Rio Uatumá, a stream between the Trombetas and the Negro. They dip toward the Amazon at a low angle—about five degrees. At Ereré and elsewhere they are cut by dikes of diabase. South of the Amazon the Devonian rocks are believed to be exposed on Rio Mauéassú south of Laranjal, and on the Tapajos south of Itaituba; but no fossils have yet been found in these particular areas, and there is, therefore, doubt about their precise age.[9]

In Paraná and southern São Paulo the Devonian rocks seem to rest directly on the Brazilian complex and dip gently westward beneath the Permian. The rocks are conglomerates, sandstones, and shales. The diamonds found in Paraná are supposed to come from the basal conglomerate. In Matto Grosso the Devonian rocks are sandstones and shales resting unconformably on rocks of the Brazilian complex and dipping gently eastward. In Bahia the Caboclo shales of Branner are supposed to be Devonian, but thus far they have yielded no fossils.[10]

Economic geology of the Devonian.—The Devonian rocks contain the conglomerates of Paraná from which the diamonds of that state are supposed to be derived.

The Caboclo shales of the interior of Bahia are available for the manufacture of Portland cement.

Elsewhere the Devonian beds are not known to contain anything of special economic importance.

CARBONIFEROUS

General observations.—Fossiliferous Upper Carboniferous beds are exposed on the lower Tapajos in the State of Pará, and on some of the smaller streams to the west of Tapajos, notably at Pedra do Barco and at Frechal, and also on the northern side of the Amazon on the rios Uatumá, Jamundá, and Trombetas. The geology and fossils are described by Chandless, Derby, Katzer, Ossat, and Tschennede.

All of the Brazilian rocks certainly known to be of Carboniferous age belong to the Upper Carboniferous and are confined to the areas mentioned. Other areas shown as Carboniferous on Katzer's map of Pará

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[9] F. Katzer: Geologie des Unteren Amazonas Gebietes, p. 215.

[10] Geographical Journal, August, 1911, pp. 151, 258; Amer. Jour. Sci., vol. xxxi, June, 1911, p. 481.

lack confirmation. Dr. Lisboa[11] credits Gonzaga de Campos with the report of Carboniferous extending south and west from the Tapajos area to Rio Theodoro just north of south latitude eight degrees, as indicated by dotted lines and the question-mark. Rocks in São Paulo and Paraná formerly called Carboniferous by Derby are now known to be of Permian age, while the diamond-bearing beds of Bahia referred provisionally to the Carboniferous by Branner have not yet yielded any fossils, and the age of those particular beds must still, therefore, be considered as doubtful.

In the Amazon region the Carboniferous rocks are shales, sandstones, and limestones; the fossils are found in the limestones and are all marine forms. At Itaituba the limestone is eight meters in thickness. The total thickness of these Carboniferous rocks in the Amazon basin is about 600 meters. No coal-bearing beds have been found in them.

The Bahia beds referred with doubt to the Carboniferous are the pinkish quartzites, sandstones, and conglomerates from which diamonds and carbonados are obtained. The rocks are gently folded over much of the diamond district and in some places they are closely folded and faulted. On account of their resistance to weathering they have a marked effect on the typography of the region in which they occur.

These quartzites, which are here tentatively referred to the Carboniferous, are of much geologic importance and interest aside from the fact that they are the rocks from which the diamonds and carbonados of Brazil are derived.

Bearing in mind that the Carboniferous age of the group of rocks here discussed has not been definitely settled, and that we have no paleontologic evidence of their age, it is nevertheless important to bring together such evidence as we have of the age, character, and distribution of this series.

In the State of Bahia the structural features of these beds, their relation to those above and below them, and their areal distribution are fairly well outlined in the papers of Branner, Crandall, and Williams. But between the *Chapada diamantina* of Bahia and the diamond fields of Minas Geraes is an area about which we have very little geologic information, and practically none that would enable us confidently to tie together with the necessary structural details the two regions. Certain facts, however, lend strong support to the theory that the diamond-bearing quartzites of the Bahia region are simply the northward extension of the diamond-bearing quartzites of Minas that are exposed and known to contain diamonds at Grão Mogol. These facts are here brought together.

[11] O problema do combustivel nacional. Rio, 1916, fig. xiv.

It has been established beyond question that the diamonds and carbonados found in the Bahia region come directly from the false-bedded pink quartzites.[12] That diamonds are found in the quartzites at Grão Mogol is equally well established.[13] That the quartzites of Bahia are the same as those at Grão Mogol is far from being a new theory. It was probably first brought forward by Helmreichen, whose paper was written in 1843 and published in 1846. Helmreichen's theory was based on what he saw at Grão Mogol and on what he heard about the geologic conditions in Bahia.[14] But, like many others, he supposed the quartzites of Grão Mogol were the old Paleozoic itacolumites of the Ouro Preto region. He adds that the following places are well known for the occurrence of diamonds:

1. Burity Quebrada, on the eastern spur of the Serra do Grão Mogol.
2. Cabeceiras do Corrego da Onça, on the western spur.
3. Corral de Pedra, on the eastern spur of the Serra do Peixe Bravo.
4. Serrinha Nova, between Rio Verde and Rio Pardo.
5. Boqueirão das Barreiras, western spur of Serra do Salto.

The places mentioned are all on or near the watershed that runs almost due north from Grão Mogol toward the city of Caiteté, in the State of Bahia, and seem to tie up the diamond-bearing quartzites of Minas with the diamond-bearing quartzites of the *Chapada diamantina* west of Paraguassú, Bahia.

It should be kept in mind, in dealing with the geology of this area, that there are several distinct series of quartzites thereabout that may readily be mistaken one for the other, both on account of their general resemblance and on account of their topographic prominence.

Economic geology of the Carboniferous.—The economic products of the Carboniferous of Brazil are limited to the diamonds and carbonados of Bahia and to the diamonds of that part of northern Minas Geraes which is supposed to be correlated with the diamond-bearing quartzites of Bahia. The evidences of the origin of the diamonds and carbonados are given briefly under the head of "Carboniferous" and under the State of Bahia. The diamond-bearing beds are not all equally rich.

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[12] O. A. Derby: The geology of the diamond and carbonado washings of Bahia. Economic Geology, vol. i, November-December, 1905, pp. 134-142.

J. C. Branner: The economic geology of the diamond-bearing highlands of Bahia. Engineering and Mining Journal, May, 1909, pp. 87, 981, 1031.

Roderic Crandall: Notes on the geology of the diamond region of Bahia, Brazil. Economic Geology, May, 1919, vol. xiv, pp. 220-244.

[13] Virgil V. Helmreichen: Geognostische Verkommen der Diamanten . . . auf der Serra do Grão Mogol. Wien, 1846.

H. Gorceix: Gisement de diamants de Grão Mogol. Bul. Soc. Géol. de France, vol. xii, pp. 538-545. Paris, 1884.

[14] V. von Helmreichen: Geognostische Verkommen der Diamanten, etc., pp. 63-65. Wien, 1846.

The opinion prevails in the diamond region of Bahia that the coarse conglomerates yield the largest diamonds and carbonados, while the fine grained sandstones yield only small ones.

It has been hoped that coal might be found associated with the Upper Carboniferous rocks of the Amazonas region, but thus far no such beds have been discovered, and the fact that the beds known are of marine origin does not encourage the hope of coal being found there.

Limestone is common in the Carboniferous rocks of the Amazonas region.

PERMIAN

General observations.—The Permian is *par excellence* the Brazilian series; rocks of Permian age cover large areas in Maranhão, Piauhy, Ceará, Bahia, Goyaz, Minas Geraes, São Paulo, Paraná, Santa Catharina, Rio Grande do Sul, and Matto Grosso, making an enormous total. Fossils from the Brazilian Permian are described by Unger, Brongniart, Carruthers, Cope, Derby, Lisboa, MacGregor, Osborn, Renault, Z. H. Scott, Seward, Solms-Laubach, David White, and Woodward.

The division of the Permian into Upper and Lower Permian on the geological map is based on what appears to be a clearly defined and easily recognized distinction. In northern Brazil, Small shows a well marked unconformity between the Upper Permian, which is exposed over most of eastern Piauhy, and the Lower Permian in the Serra Grande that lies along the boundary between Piauhy and Ceará. The only uncertainty about this classification—and it is a serious one—is that the Serra Grande series has never yielded any fossils, and its reference to the Lower Permian is therefore in doubt. In southern Brazil the Upper Permian is characterized by the fossils *Stereosternum* and *Mesosaurus* and by siliceous beds and concretions, while the Lower Permian contains the *Glossopteris* flora, the coal beds, and in some places in São Paulo and Paraná it contains well marked evidences of glaciation. The evidences of glaciation are best described by Woodworth, the title of whose book is given in the bibliographic list under São Paulo. Thus far, unquestioned evidences have been found only in the States of Santa Catharina, Paraná, and São Paulo; but Dr. Lisboa found in Minas Geraes what seem to be evidences of glaciation in the region between Rio Borrachudo and Rio Abaeté.[15] In São Paulo and from there southward the Permian beds dip gently westward, while characteristic Permian fossils, notably *Stereosternum tumidum*,[16] found near Villa Rica, Paraguay, and *Productus* and *Spirifer*

[15] M. A. R. Lisboa: The occurrence of faceted pebbles on the central plateau of Brazil. Am. Jour. Sci., January, 1907, vol. xxiii, pp. 9-19.

[16] Frech in Lethea Geognostica, Th. I, 2 Bd., Lief 3, p. 460.

poststriatus, the last two from mountains on the Matto Grosso frontier,[17] lead to the conclusion that the Permian probably underlies all of the Paraná Valley west of Paraná and Santa Catharina, and that some of the limestones of southern Matto Grosso, called "Bodoquena" by Dr. Lisboa, may yet prove to be of Permian age.

The rocks of the Permian in Brazil seem to be mostly sandstones and shales slightly disturbed, but they include extensive beds of limestone—all of them cut here and there by eruptive dikes. In São Paulo, Paraná, and Santa Catharina the Lower Permian contains glacial till with striated boulders. The glaciated Permian beds in the States of São Paulo and Paraná are described by Prof. J. B. Woodworth, to whose paper the reader is referred.[18] The base of the Permian is fairly well located across the State of São Paulo, but north of the São Paulo-Minas frontier the eastern margin of the series has been tentatively located with difficulty and with doubt. The evidence of the northward extension of the beds recognized in São Paulo as Permian are here brought together. It is assumed that the faceted boulders found by Dr. Lisboa in the region between Rio Borrachudo and Rio Abaeté may have come from Lower Permian glacial beds, as he suspected;[19] for Dr. Lisboa distinctly repudiated the idea of Pleistocene glaciation in connection with these boulders, and that the region in which the faceted pebbles were found had been glaciated in Permian times was definitely taken into consideration by him. After mentioning the Permian deposits of southern Brazil, he adds:

> "But in the central region in the great basin of the upper São Francisco they (the Permian beds) have never been identified. So far as the geology of the region is known, however, there is nothing positively against this hypothesis (of Permian glaciation), and any undoubted observation that supports it will be of great geologic importance for this country." [20]

Thus Dr. Lisboa was the first geologist to suspect and to suggest the full meaning of the Permian data in the State of Minas Geraes.

Additional notes by Dr. Francisco de Paulo Oliveira on the geology of the region between Pitanguy and the lead mines of Ribeirão do Chumbo, an affluent of Rio Abaeté, are of interest in this connection;[21] at page 48 he says:

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[17] J. V. Siemiradski: Geologische Reisebeobachtungen in Südbrasilien, p. 39.

[18] J. B. Woodworth: Geological expedition to Brazil and Chile. Bul. Mus. Comp. Zool., vol. lvi, no. 1. Cambridge, Mass., 1912.

[19] M. A. R. Lisboa: The occurrence of faceted pebbles on the central plateau of Brazil. Am. Jour. Sci., January, 1907, vol. xxiii, pp. 9-19.

[20] Miguel A. R. Lisboa: Occorrencia de seixos facetados no planalto central brasileiro. Annaes da Escola de Minas de Ouro Preto, no. 8, pp. 25-39. Ouro Preto, 1906.

[21] Francisco de Paula Oliveira: Exploração das minas de galena do Ribeirão do Chumbo. Annaes da Escola de Minas de Ouro Preto, no. 1, Rio de Janeiro. 1881, pp. 35-94.

"Upon the shales rest the red sandstones like those near Abaeté on the banks of the Borrachudo and the Chumbo. They belong to a formation above the clay shales. Between the serra do Capacete and the banks of the Indaiá there are rolled stones on the tops of the mountains that show the great action of water in this part of the province. . . . Finally, intercalated with the clay shales are enormous beds of limestone, and above them ferruginous conglomerates. These conglomerates are seen near the village of Dores along much of the road leading from the village of Carmo to the town of Dores."

The conglomerates and water-worn rocks mentioned by Dr. Oliveira are in the region in which Dr. Lisboa later found the faceted pebbles.

Dr. Antonio Olyntho, speaking of the watershed between the Abaeté and the Borrachudo, mentions "uma argilla branca com caprichosos arabescos." [22]

In connection with the subject of Permian glaciation in Minas the following is of especial interest: The French geologist Francis de Castelnau, who went from Pitanguy to Bom Despacho, in the State of Minas, in January, 1844, made the following notes on the geology: After leaving the city of Pitanguy, he crossed the Rio Pará and passed fazenda Santa Cruz. He then says:[23]

"On the 22d we made three leagues in the same direction. The formation is clay shale, probably resting upon gneiss. One league from Santa Cruz (fazenda) one begins to find scattered about a great quantity of granite blocks that look like erratics; they can not come from slides ('d'eboulement') from the mountain, for there are none in the vicinity. Never having seen anything of the kind in the whole course of our expedition, it is only with doubt that we refer the rocks in question to such an origin; it is very likely that they owe their origin to some local phenomenon. . . . The formation in general is clay shale (schiste), gray, ochreous, and reddish, dipping to the east, but half way between Trigueira and Bom Despacho the ground is covered by a sheet (coulée) of rose-colored granite which looks like a kind of syenite. On both sides of the road one sees over the plain a considerable quantity of granite blocks that have the appearance of being erratic. The land is rather flat on the whole, and one sees these blocks on the steep slopes right away up to the hilltops."

These observations by Castelnau must be regarded as especially suggestive and valuable in connection with the subject of Permian glaciation in Minas. A little farther southwest, on the road between Formiga and Bambuhy, Pohl noted red and yellow clays and clay shales.[24]

Mr. H. E. Williams, of the Serviço Geologico do Brasil, in a private letter dated August 26, 1918, writes:

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[22] Viagem aos terrenos diamantiferos do Abaeté. Annaes da Escola de Minas, no. 4, p. 141.

[23] Francis de Castelnau: Expedition dans les parties centrales de l'Amerique du Sud. Historie du Voyage. vol. i, pp. 276-278. Paris. 1850.

[24] Joh. Em. Pohl: Beyträge zur Gebirgskunde Braziliens. Wien, 1832.

"Mr. Draper has been up about Areado, and, following down the Pindahybas, he and Mr. Pontie found an exposure of conglomerate four or five meters thick with big boulders of granite. Draper calls it the Dwyka. This is not far from where I found a small exposure of the same nature south of Areado. I have word of similar beds of conglomerate on the north side of the Caboclo above the Fabrica de Oliveira."

Mr. F. W. Bunyan, who visited both regions, tells me that the rocks exposed at the junction of Rio das Velhas and Rio São Francisco are remarkably like the Permian till beds at Itararé and Faixina, in southern São Paulo.[25] This observation was made without any suggestion or question by me. Upon receiving this information in regard to a particular locality, I looked up the notes of other observers made at that place with the following results:

Dr. Theodoro Sampaio, who visited this place in 1879, says he found on the sides of the Serra de Manga "um schisto avermelhado que aqui parece constituir o embasamento do planalto e muito seixo rolado." [26]

At Jequitahy, a village nine leagues east of the mouth of Rio das Velhas, Derby found "a pudding-stone containing well worn boulders of quartz, jasper, gneiss, quartzite, and amorphous limestone, some of them of great size." [27]

At the mouth of Rio das Velhas, James W. Wells, an English engineer, observed "a sheet of unstratified clay, interspersed with pebbles and boulders overlying the rock in places. . . . The boulders are usually masses of a kind of greenstone . . . and they are entirely foreign to the rocks they often rest upon." [28]

The demarcation between the Lower and the Upper Permian seems to be well defined in the State of São Paulo, but north of there, for lack of fossils, no separation can be made save on the hypothesis that the same division probably continues northward into Minas. A comparison of the order of the beds as given for the rocks by Dr. Oliveira in the article cited above[29] shows the presence of a bituminous shale that brings to mind the Iraty bituminous shale so characteristic of the base of the Upper Permian in São Paulo and Paraná. The order of the rocks as given by him is:

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[25] Letter of December 19, 1917.

[26] "O Rio de São Francisco e a Chapada Diamantina," p. 89.

[27] O. A. Derby: Reconhecimento geologico de Valle do São Francisco, p. 5 do annexo ao Relatorio de W. Milnor Roberts . . . sobre o exame do Rio São Francisco. Rio de Janeiro, 1880.

Also in the Archivos do Museu Nacional, vol. iv, p. 102.

[28] J. W. Wells: Three thousand miles through Brazil, vol. ii, p. 373. London, 1886.

[29] Annaes da Escola da Minas, no. 1, p. 53.

5. Ferruginous conglomerates and sandstones.
4. Clay shales.
3. Bituminous shales.
2. Limestones.
1. Shales at the base.

Unfortunately he does not tell where this bituminous shale was seen. A bituminous shale is also reported by Dr. Lisboa in Maranhão.

These notes and observations are all extremely interesting and suggestive, and it is hoped that the evidences of glaciation and of the Permian age of the beds in question may soon be examined and definitely settled by a geologist thoroughly familiar with glacial phenomena.

The evidences of the structural relations of the great limestone beds of the upper Rio das Velhas to the Permian beds to the west of them are not abundant, but they seem to be conclusive. Eschwege, whose obser-

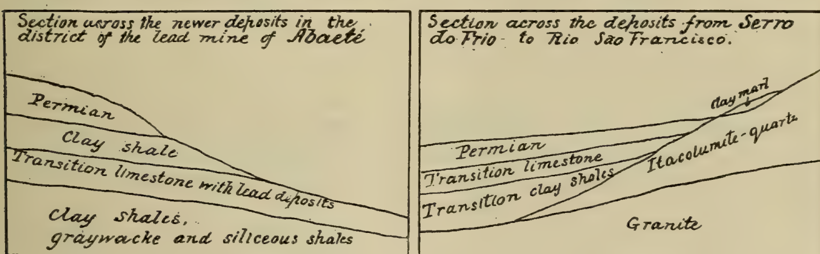

FIGURE 2.—*Two Sections from Eschwege's Beiträge zur Gebirgskunde Brasiliens*

The names in the original are here translated, and the greatly exaggerated vertical scale is reduced to two-fifths of the original.

vations and judgment must be accepted in all seriousness, gives two sections in which he shows the relative position of the rocks of the Rio das Velhas and of those at the lead mines of Abaeté west of Rio São Francisco. These two sections are here reproduced,[30] and attention is directed to his clear conviction that the limestones on both sides of the São Francisco underlie or form parts of the Permian beds. Whether the limestones and his transition ("Uebergangsthonschiefer") and other shales really make part of the Permian is a question that can not be settled at present. Eschwege's own views seem to be expressed in a footnote at page 488 of his Beiträge zur Gebirgskunde. He there says:

"One must also not forget the wide-spread distribution of the transitional areas of clay shales and limestones in the province of Minas Geraes, in the

[30] W. L. von Eschwege: Beiträge zur Gebirgskunde Braziliens. Berlin, 1832 (plate no. 3).

region of Rio São Francisco and in that of the Rio Tieté, in the province of São Paulo."

From this it is inferred that he means to correlate the clay shales and limestones of the upper São Francisco with what we now know to be the Permian beds of São Paulo.

Gerber leaves no doubt about his views in regard to his "transition formations," for he says:[31]

"The greater part of northwestern Minas, the basins of the Rio São Francisco and Rio das Velhas from Lagoa Santa belong to this (transition) division, whose principal representative is the traumatic shale. The beds of this formation are almost entirely horizontal, and at divers places there are interbedded with them limestones whose general masses are spherical [he probably means lenticular], and exhibit horizontal stratification."

Though Lund spent many years at Lagoa Santa, in Minas, near the base of the Permian, the only expression of his that seems to relate to this subject is where he speaks of a hill at whose south base were great quantities of limestone blocks. He adds:

"I mention this case, by the way, only because it corresponds with many others that I have seen, and because it shows that a great inundation that covered this part of Brazil with its last layer of earth, and that dislocated enormous rock fragments, had a north-south direction in these regions." [32]

In regard to the rocks of the Serra do Maquiné, which is on the left side of Rio das Velhas, some thirty kilometers south of Curvelho, he says that "at the base of the mountain one finds the same rock as on the surrounding plain—transition clay shales alternating with siliceous shales dipping eastward ten degrees (page 63). The limestone in which Maquiné cave occurs "alternates with beds of clay or siliceous shales with gypsum crystals. These (shale) beds are generally not so thick as the limestones." [33]

Owing to his exploration of the Rio das Velhas, the observations of Em. Liais on the geology along that stream are worthy of especial attention. He says:[34]

"Mais si maintenant, en descendant la vallée du San-Francisco, nous accompagnons ces calcaires à partir de ceux qui se trouvent ainsi dans le haut de son bassin entre l'Abaéthé et le Rio das Velhas, nous les verrons se présenter d'une manière identique quant à leur structure, leur aspect, leur grottes, leurs puissance et leur distribution dans toute l'extension du cours du fleuve, et ils y forment comme une espèce d'horizon géologique très facile à suivre et à accom-

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[31] Henrique Gerber: Noçoes geographicas e administrativas da provincia de Minas Geraes. Reimpressão da 1a ed. de 1863. Hannover, 1874, p. 19.

[32] P. W. Lund: Grutas calcareas, etc. Annaes da Escola de Minas, no. 4, p. 12. Rio de Janeiro, 1885.

[33] P. W. Lund: Annaes da Escola de Minas, no. 3, pp. 63-64. Rio de Janeiro, 1884.

[34] Emmanuel Liais: Climats, géologie, fauna, etc., du Brésil. Paris, 1872, p. 179.

pagner. Constamment, nous retrouverons ces mêmes calcaires des deux côtés de la vallée du San-Francisco, et ils apparaissent souvent à la bas d'une dépôt de grès et de schiste argileux à couches presque horizontales, qui repose sur eux et dans lequel la dénudation a creusé le bassin du fleuve et de ses affluents."

Notes made by Dr. Antonio Olyntho at Lapa do Chumbo, five kilometers southwest of Sete Lagoas and close to the margin of the Permian,[35] tell of "um veeiro de quartzo encaixotado entre camadas de schisto, tudo intercalado em uma montanha calcarea," and "As camadas de schisto têm para cima a altura de 3 a 4 metros, e acima d'elles vêm a

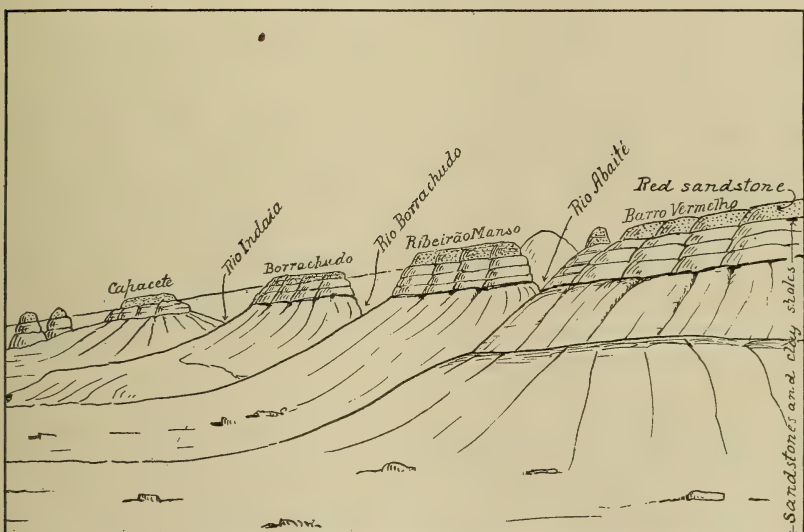

FIGURE 3.—*The Mountains of the Diamond District of Abaité*

The view is taken from near Toldas, six leagues east of Serra do Barro Vermelho. After P. Claussen.

montanha calcarea." These exposures leave no doubt about the shales and the limestone being interbedded.

This interbedding of the shales and limestones is noted by all the geologists who have crossed the basin of the upper Rio São Francisco, especially on rios Indaia, Borrachudo, Abaeté, and on the São Francisco.[36] Particularly impressive and enlightening are the section given by Claussen, which is here reproduced,[37] and his observations and conclusions in

[35] Antonio Olyntho dos Santos Pires: Viagem aos terrenos diamantiferos do Abaeté. Annaes da Escola de Minas, no. 4, pp. 145, 146. Rio de Janeiro, 1885.

[36] See Lisboa, Oliveira, Antonio Olyntho, and Claussen.

[37] P. Claussen: Notes géologiques sur la province de Minas Geraes. Bul. Acad. Royal de Bruxelles, vol. viii, no. 5, pl. 1, Brussels, 1841.

regard to the Permian beds, which he called the "terrain de transition" (page 7).

Claussen's section represents the geology right across the Permian basin, including the whole region between Serra do Capacete and the Serra do Barro Vermelho. Of the "terrain de transition" he says (page 7):

"Le terrain calcareux de transition est composé de couches a peu pres horizontales de phyllades argileux, petrosiliceux et macignos.[38] Elles contiennent, spécialement dans leurs assises inferieurs, des couches puissantes de calcaire noir et gris. Presque toutes les inégalités de ce terrain sont dues aux effets de la dénudation, et cela donne um aspect tout particulier au pays, en formant de grands plateaux sur des montagnes cotoyées de terrasses. . . . Ce terrain constitue à peu près le tiers du sol de la province de minas Geraes."

And it should be remembered that Claussen lived in Minas some twenty years (page 1), and that he traveled widely, while his paper showed that he was a careful and discriminating geologist.

On the east side of the Rio São Francisco these limestones and interbedded shales, here referred to the Permian, extend from Santa Luzia in Minas northward to about 50 kilometers north of 14 degrees south latitude—that is, to a point about 75 kilometers northeast of the city of Carinhanha. On the west side of the São Francisco the limestones end a few kilometers north of Carinhanha.[39]

General conclusions.—The Permian beds have been definitely determined from fossils, and traced out stratigraphically from the southern part of Rio Grande do Sul to the northern part of São Paulo. North of São Paulo the base of the series has been approximately located from the notes of geologists as far as 14 degrees south latitude on Rio São Francisco, while in the *Chapada diamantina* east of the Rio São Francisco rocks believed to belong to the Permian have been located by the writer and his assistants, Crandall and Williams, over the region between 12 and 14 degrees south latitude.

In the southern states several divisions have been recognized locally, but two divisions are readily identified by the fossils *Stereosternum* and *Mesosaurus* and by the flint beds found in the upper, and by the *Glossopteris* flora and the glacial beds found in the lower division. In northern Brazil the upper division is characterized by the fossils *Psaronius* and *Sigillaria,* but no fossils have yet been found in northern Brazil in what are referred tentatively to the Lower Permian.

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[38] Macigno is defined by Littré as a rock composed of quartz, mica, clay and iron hardened by a calcareous cement. Vilanova y Piera says it is a hard sandstone of feldspar, mica, cemented by a siliceous marl, sometimes green, sometimes black.

[39] It should be noted that the Permian limestones do not connect with those at Bom Jesus da Lapa. The Bom Jesus exposure is entirely isolated.

The Permian rocks are sandstones, clay shales, and limestones cut at many places by eruptive dikes. For the most part they are approximately horizontal, and they seem to be of land or fresh-water origin, though what are supposed to be brackish water fossils have been found in them at Rancho Grande and Lageadinho, on Rio Caçador near the old Iraty colony, and Mojolinho and at several other places, all of them in the State of Paraná.[40]

Topographically the upper Permian beds form vast stretches of table lands that are deeply eroded by streams and supporting a sparse vegetation.

Though fossils have been found in the Permian in the north and south of Brazil, none has yet been identified from the great area covered by these rocks in the State of Minas Geraes. The fact that poorly preserved but unrecognizable fossils are reported from this region by both Claussen and Liais leads to the reasonable hope that a careful search for them may yet be rewarded with unquestionable evidence of the age of the deposits and of the conditions under which they were laid down.

Prior to 1840 Claussen found the impression of a univalve shell in sandstone in the region of the upper Rio Abaeté, but he was unable to identify it, and it was deposited by him in the National Museum at Rio de Janeiro.[41] Liais also reports fossils in this region, and as his account of them is the fullest and almost the only one we have, it is given here at some length.[42]

"A short distance from Pitangui and near Abbadie I have seen nodular and bituminous limestones with undeterminable traces of fossils, among which I could distinguish small lenticular bodies from two to three millimeters in diameter, which seemed to me to belong to the foraminifera, although the alteration prevents my being able to say so definitely. Near Lapa dos Urubus, on the right side of the Rio das Velhas, a short distance below the confluence of the Paraúna, I have seen a marble with a white ground, the beds standing on end and cut by reddish and gray veins. On polishing pieces of this marble I have recognized fragments of univalve shells, but quite undeterminable. In another bituminous limestone of the same horizon I have found traces of cirriped crustacea more recognizable and belonging to the genus *Pollicipes*, which indicates a marine origin for these limestones and places them in the secondary epoch.

"In the *macignos*, on the borders of Rio Abaeté, other fossils are found which also show the formation in question to be marine. There are impressions of the genus *Ostrea*. M. Claussen has already mentioned them, and in

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[40] Euzebio de Paulo Oliveira : Geologia do Estado do Paraná, pp. 130-131. Rio de Janeiro, 1916.

[41] P. Claussen : Notes géologiques sur la province de Minas Geraes. Bul. de l'Acad. Royale de Bruxelles, vol. viii. no. 5, p. 9. Bruxelles, 1841.

[42] Emmanuel Liais : Climats, géologie, etc., du Brésil, pp. 147-148. Paris, 1872.

my trip on the upper São Francisco I have seen an impression of an oyster of good size (d'assez grande taille) and remarkable not only for the thickness of its shell, but also for the great prominence of the spire, which places it close to the grypheas. I shall give this species the name *Ostrea abœthensis* from the name of the river basin in which I found it. At the same place I noted a great number of impressions of the same species.

"In the *macigno* sandstones I have likewise seen less well preserved impressions of divers polyps and fragments of undeterminable univalve shells of considerable size. . . .

"Everything shows, therefore, that the metamorphic limestones of the province of Minas Geraes and belonging to the stage of which we speak are not older than the Cretaceous."

Mr. Derby, in referring to these statements, expresses the opinion that Mr. Liais erred in the identification of the fossils.[43]

Whether Liais erred or not, his notes and those of Claussen clearly point out the region in which fossils may be sought and to which field geologists should give their careful attention. If Liais is correct in the identification of his fossils, there is an area of Cretaceous rocks in the region where he found them, but it does not necessarily follow that there are no Permian beds beneath them.

Economic geology of the Permian.—The coal beds of Paraná, Santa Catharina, and Rio Grande do Sul are among the important economic products of the Permian in Brazil. Here, too, belong the Iraty bituminous shales of the southern states. The Permian limestones are widespread and are likely to be a source of national importance for the manufacture of Portland cement.

It seems quite possible that some of the important occurrences of diamonds in Brazil are in the glacial beds at the base of the Permian.

TRIASSIC

The Triassic rocks, so far as they have been recognized in Brazil, are known as the Botucatú, a name given them by Gonzaga de Campos for the Serra de Botucatú, in the State of São Paulo. They are soft reddish sandstones, usually horizontal, but more or less faulted, and associated with sheets and dikes of diabase eruptives. These beds attain a maximum thickness of 500 meters or more, but averaging from 100 to 300 meters. They cover large areas in the States of São Paulo, Paraná, Santa Catharina, Rio Grande do Sul, Matto Grosso, and Goyaz, and probably also in Piauhy and Maranhão.

The only fossils thus far reported from the Triassic of Brazil were

[43] Reconhecimento geologico do Valle de São Francisco. Por O. A. Derby. Pagina 9 do annexo ao Relatorio de W. Milnor Roberts sobre o Rio São Francisco. Rio de Janeiro, 1880.

found near Santa Maria da Bocca do Monte, in the State of Rio Grande do Sul, and at São José do Rio Preto, in São Paulo. (See Smith Woodward and R. Von Ihering.)

CRETACEOUS

General observations.—Fossiliferous Cretaceous beds are found in a narrow belt along the coast of Parahyba, Pernambuco, Sergipe, and Bahia. In the States of São Paulo, Paraná, Santa Catharina, Rio Grande do Sul, and in southern Matto Grosso Lower Cretaceous beds (named Baurú by Gonzaga de Campos) cap the hills and cover large areas. The only fossils found in the Baurú beds suggest that they correspond to the Wealden of Europe. (See Pacheco.) In the Serra do Araripe, along the southern frontier of Ceará, Cretaceous beds contain well preserved fossil fishes. The rocks in the Serra do Araripe are nearly horizontal sandstones and limestones that extend into the adjacent States. (See Jordan and Branner.)

The areas in Matto Grosso colored as Cretaceous on the map—the Parecis sandstones—are not yet certainly known to be such, for no Cretaceous fossils have been found in them. The views of Euzebio de Paulo Oliveira are followed.[44]

The following authors have written on the Cretaceous of Brazil:

Agassiz	Hyatt	Oliveira, E. (Matto Grosso)
Alport	Jordan	Rathbun
Branner	Loriol	White, C. A.
Cabrillac	Marsh	Williston
Cope	Mawson	Woodward
Douvillé	Morris	

Economic geology of the Cretaceous.—In the State of Sergipe Cretaceous limestones are abundant and are available both for building stones and for the manufacture of lime and of Portland cement.

In the Chapada do Araripe the Cretaceous contains important beds of limestone. Limestones of local importance also occur in the Cretaceous of Pernambuco and Parahyba.

TERTIARY

General observations.—Beds of Tertiary age occur in Acre, where they are fresh-water or land deposits. In Amazonas fossils show some of the Tertiary beds to be brackish water deposits. In Pará, Maranhão, and Rio Grande do Norte fossils show the Tertiary deposits to be of marine

[44] Reconhecimento geologico do noroeste de Matto Grosso por Euzebio Paulo de Oliveira, pp. 31, 69. Rio de Janeiro, 1915.

origin, and it is assumed that the corresponding sediments forming a similar belt in Ceará are also marine. Marine fossils have been found also in the Tertiary beds in Parahyba, Pernambuco, Alagoas, and Bahia, and it is supposed that some of the coastal sediments in Sergipe, Espirito Santo, Rio de Janeiro, and along the coast to the south are likewise Tertiary. In Rio de Janeiro, São Paulo, and Minas are extensive Tertiary lake deposits, and near Ouriçanguinhas, Bahia, lake deposits overlie the marine Cretaceous.

The Tertiary fossils have been described by—

Alport	Jenkins	Rathbun
Arnold	Jordan	Reinhardt
Conrad	Jones	von Ihering
Cope	Krasser	Warming
Dall	Lacerda	White, C. A.
Ethridge	Lund	Winge
Gabb	Lutken	Woodward
Gervais	Morris	
Gürich	Quatrefages	

Economic geology of the Tertiary.—In the coastal belt from Bahia northward the Tertiary sediments are liable to be of value at many places as sources of underground water. At several places in the States of Bahia and Alagoas the Tertiary beds include bituminous shales that may eventually be of economic importance. In Minas and São Paulo the Tertiary lake deposits also contain lignites and bituminous shales. These shales were formerly used at Taubaté for the manufacture of gas. Clays for the manufacture of bricks, tiles, sewer pipes, and common pottery are abundant in the Tertiary. See also under Amazonas.

Petrography

Under the head of petrography nothing need be said of the old writers whose geologic classifications were based on lithology. All of the early writers on Brazilian geology used terms that have long been discarded. Most of the modern work on this branch of geology was done by Hussak, whose papers are given under the States of Minas, São Paulo, Rio de Janeiro, and Goyaz. Following are the modern petrographers who have written on Brazilian rocks:

Bauer, H. E.	Hovey
Derby	Hussak
Gill (Fernando de Noronha)	Iddings
Gorceix	Kemp
Graeff	Laerne
Gumbel (Fernando de Noronha)	Machado

Merrill, G. P. (Rio Grande do Sul, Santa Catharina, and Paraná)
Prior (Trindade)
Reiman
Renaud
Ridley
Rosenbusch
Turner (Pernambuco)
Washington (Bahia)
Williams, G. H. (Fernando de Noronha)
Wright

Outlines of the general and economic Geology and Bibliography by States

GENERAL OBSERVATIONS

In the text the states are arranged alphabetically.

Those who have occasion to use the geologic map of Brazil are also liable to have occasion to use what has been published on the geology of the individual states or of other limited areas. For that reason there is given a partial bibliography of the geology of each of the states.

Under each state is given a brief outline of its general geology, and this outline is followed by a short statement of what is known of its economic geology. If the information given is often very meager, it is because only meager information is available.

In the bibliographic lists the titles are arranged alphabetically by authors.

All the papers referring to the geology of the various states are not given in the state lists for the reason that many of them are merely repetitions, in one form or another, and treat of the geology only at second or third hand. The idea of giving the titles at all is partly to show the authorities for some of the data used in the geological map of Brazil and partly to enable those who wish to consult the original authorities to find them readily and to obtain fuller information if it should be required.

If additional titles are wanted, most of them can be found in the author's bibliography of the geology of Brazil, published in the Bulletin of the Geological Society of America, volume 20, pages 1-132, 1909. It should be remembered, however, that many valuable papers have appeared since that list was published. Unfortunately, many of the contributions to the geology of Brazil have appeared only in the daily papers in Rio de Janeiro and are therefore difficult of access to persons outside of that city.

The island of Fernando de Noronha is politically a part of the State of Pernambuco, and for that reason the titles referring to that island are included in the State of Pernambuco and are followed by the word (Fernando) in parentheses, except when the title makes clear its relation to that island.

The Brazilian island of Trindade, in latitude 20° 30′ south, 29° 25′

west, belongs to the Federal Union, and the few titles relating to that island are given under Rio de Janeiro, in which the federal district is also located.

ACRE

Previous investigations.—Our knowledge of the geology of the territory of Acre is derived almost exclusively from the notes of William Chandless, given in his account of explorations of the upper Purus and the Aquiry. A little sidelight may be had on the geology from the notes of Evans, Church, Keller, and Euzebio de Oliveira on the geology of the falls of the Madeira River. An important contribution is the discussion by Gürich of the age of the deposits along the upper reaches of the Purus. Those beds had been referred by Agassiz to the Cretaceous, but Gürich shows conclusively that they are late Tertiary.

General geology.—With the possible exception of the foothills in the western and southwestern parts of the territory, its entire area is covered by late Tertiary deposits—mostly undisturbed sands and clays through which wind sluggish streams. The entire area is covered by dense forests and there are no roads. The population is sparse and all travel is by water.

There is no doubt about there being wide zones of alluvial deposits along the larger streams, but there is very little or no available information on the subject.

In the southwestern corner of the territory the frontier seems to be in the foothills of the Andes, but nothing is known of the ages of those rocks, and that area is therefore left blank on the map.

Economic geology.—Nothing trustworthy has been published on the mineral resources of Acre territory. Gold has been reported from some of the streams heading in the hilly regions in the west and southwest.

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W. Chandless: Apontamento sobre o Rio Aquiry, affluente do Rio Purus. Annexo (lettra n) ao Relatorio do Ministro de Agricultura, etc., pages 1-6. Rio de Janeiro, 1866.

W. Chandless: Notes of a journey up the River Juruá. Journal of the Royal Geographical Society, volume XXXIX, pages 296-311. London, 1869.

George Earl Church: The route to Bolivia via the River Amazon. 8°, 216 pages. London, 1877.

J. W. EVANS: The rocks of the cataracts of the River Madeira, etc. Quarterly Journal of the Geological Society, volume LXII, pages 88-124. London, 1906.

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FRANZ KELLER: The Amazon and Madeira rivers. Sketches and descriptions from the note-book of an explorer. By Franz Keller, engineer. 4°, xvi + 177 pages. New York, 1874. Notes on the geology.

EUZEBIO PAULO DE OLIVEIRA: Expedição Scientifica Roosevelt-Rondon. Annexo I, Geologia. Rio de Janeiro, 1915. (Estrada de Ferro Madeira-Mamoré, paginas 61-65.)

ALAGOAS

Previous investigations.—Very little has been published on the geology of the State of Alagoas. Of the three papers by Branner the most comprehensive is the one on the geology of the coast of the State, published in the Annals of the Carnegie Museum. The paper by D. S. Jordan on the fossil fishes from Riacho Doce definitely determined the Eocene age of the coastal sediments of that state for the first time. Branner's paper on the oil-bearing shales of the coast includes about all that is known of the Tertiary of the state. A few notes in Hartt's Physical Geography and Geology of Brazil, and a few by Burlamaqui on the shales at Camaragibe, together with the papers above mentioned, contain all that has been published on the geology of Alagoas.

The geology as given on the author's map of Brazil is taken almost exclusively from his own personal observations, supplemented by the notes of his assistant, Roderic Crandall, who crossed the state from Penedo to Maceio in 1908.

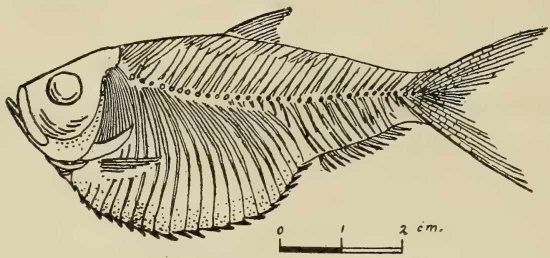
General geology.—Archean rocks are exposed over the greater part of the interior of the State of Alagoas. Tertiary sediments form the seacoast, while between is a triangular area of old Paleozoic and Permian beds. Starting at Traipú, on the Rio São Francisco, the eastern margin of the Archean area runs in a northeasterly direction past the northern end of Lagoa Manguaba, Albuquerque, Passo, and Porto Calvo, and so on into the State of Pernambuco near Barreiros. To the north and west of this line everything is Archean except some isolated hills of sedimentary rocks near the falls of Paulo Affonso.

Lapping back against this Archean area is a series of Paleozoic rocks of unknown age. This series is exposed where it is cut across by the Rio São Francisco from near Traipú to southeast of the town of Collegio. The contact of the sedimentary beds with the granite seems to be at Talhado near Traipú.[45] This Paleozoic area forms an acute triangle whose

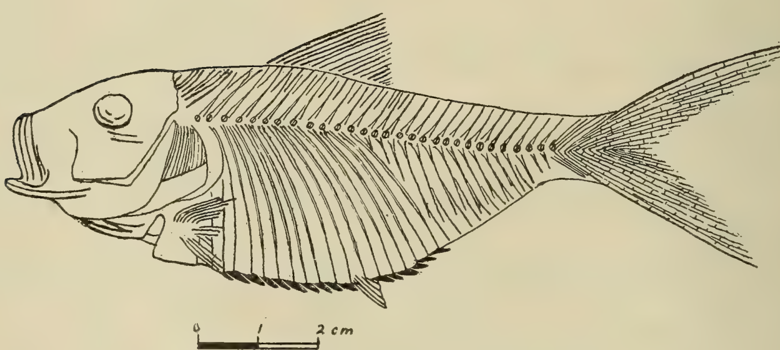
[45] R. F. Burton: Explorations, etc., vol. ii, p. 423. London, 1869.

eastern extremity is probably near the north end of Lagoa Manguaba. Resting back against these Paleozoic rocks is another wedge-shaped area of red Permian sandstones and shales which crop out at the city of Penedo, on the Rio São Francisco, and dip gently toward the ocean.

Along the railway between Piranhas and the falls of Paulo Affonso are several outliers of sedimentary rocks that are here tentatively referred to the Permian. These outliers cap the hills on both sides of the railway and extend to the northeast as far as Buique, in the State of Pernam-



Ellimma branneri Jordan



Ellimma riacencis Jordan

FIGURE 4.—*Eocene Fishes from the bituminous Shales at Riacho Doce, State of Alagoas*

buco. Along the entire Alagoas coast Tertiary sediments form a series of bluffs that reach a height of 100 meters above the sea. The rocks are mostly soft sandstones and clays, in some places false-bedded, everywhere particolored, usually horizontal, but at many places showing a landward dip. The upper part of these bluffs are probably Pliocene, but fossil fishes found in the lower shales at Riacho Doce and at other places on the immediate coast are Eocene.

The remains of extinct Pleistocene vertebrate animals are frequently found in old marshes where excavations are made for watering places for cattle.

Economic geology.—Our present knowledge of the economic geology of the state is confined to the limestones found in the Archean area of the interior, the bituminous shales of the coast, and the structural features favoring the finding of water in the area of the coast sediments.

Crystalline limestone or marble is known at Ipueiras between Quebragulo and Palmeira dos Indios (Dombré 38), at or near Colonia Leopoldina (Galvão), and on the road between Sant'Anna and Aguas Bellas. It probably exists at many other places in the Archean area of the state. Most of the lime used in Alagoas is made from corals taken from the reefs along the coast.

Coal has been reported from the vicinity of Paulo Affonso, but its existence, either there or elsewhere in the state, is doubtful.

The bituminous shales are confined to the coastal belt of Tertiary sediments. These shales are known here and there along the coast from Bica da Pedra, just east of the city of Alagoas, to Rio Persinunga, at the Pernambuco frontier. It is quite probable that they continue southward nearly to the mouth of Rio São Francisco, but they have not yet been reported from that region. No attempt has been made to utilize these shales, though a report was made on them many years ago. (See Redwood and Topley and Branner.)

The area of Tertiary sediments is one in which water may reasonably be expected—possibly artesian water in some places.

Three-fourths of the state lies in the region of the Brazilian complex—granites, gneisses, and crystalline schists—in which many minerals of value are likely to be found.

Geologic Map of Alagoas

John C. Branner, 1910.—But one attempt has been made at a geological map of Alagoas; that is by J. C. Branner and was published in connection with an article, "The geology of the coast of the State of Alagoas, Brazil," which appeared in volume VII, number 1, of the Annals of the Carnegie Museum in 1910. The map forms plate II of that paper. It is on a scale of 1 to 1,238,095; it shows only the eastern part of the State. Only four divisions of the geologic column are attempted: old crystalline, Paleozoic, Estancia, and Tertiary. The Estancia beds are there called Trias with a question. Later studies show the Estancia beds to be Permian—some of them at least.

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AMAZONAS

Previous investigations.—The map of the State of Amazonas is chiefly from the sheets published by the Inspectoria Federal das Estradas, under Dr. José Estacio de Lima Brandão, in 1913. The streams in the southeastern part of the State, especially the Gy-Paraná, Theodoro, the Tapajos, and part of the Madeira, are from the map accompanying the lectures by Colonel Candido M. de Silva Rondon, published at Rio de Janeiro in 1916.

Our knowledge of the geology of the State of Amazonas is of the fragmentary kind found in the notes of travelers along the Amazon, the Rio Negro, and the Madeira rivers and a few other of the large tributaries. Explorations in the region have been confined almost exclusively to trips made along the navigable streams, for there are very few roads in that State. The geology as shown along the extreme northern part of the map is taken from Brown and Sawkins' geological map of British Guiana and from the notes of Roderic Crandall, who lived for some time at Boa Vista, on Rio Branco.

A good résumé of the geology and physical features is given by Herbert H. Smith as an appendix to his "Brazil, the Amazons and the Coast" (pages 619-635, New York, 1879). Bates' "The Naturalist on the Amazon" is a classic, though it does not contain much on the geology. Of the titles given below, the following relate to paleontology: Boettger, Brown, Clarke, Conrad, Ethridge, Gabb, Gervais, Gürich, and Woodward.

General geology.—There are two large areas of Archean rocks in the State of Amazonas, one on the north side, the other on the south side of the Amazon River. A great synclinal fold, beginning somewhere in the State of Pará, runs along the axis of the Amazon Valley at least as far as Manaus, and in this basin are sedimentary rocks of Silurian, Devonian, and Carboniferous age, all of them dipping gently toward the axis of the valley.

The Silurian rocks are marine sediments, mostly thin-bedded sandstones, the equivalent of the Niagara of North America. On the Rio Trombetas they are best exposed at the first and second falls, in zones from six to eight kilometers wide. They are estimated to have a thickness of about three hundred meters.

The Devonian rocks of the state are coarse white and yellow sandstones and black and reddish shales, all of them dipping southward at an angle of five degrees. They have a total thickness of about two hundred meters.

The Carboniferous beds are exposed on the Jamunda and Uatuma on the north side of the Amazon and on Rio Abacaxis on the south side. They are shales, sandstones, and limestones, the last named containing marine fossils. The total thickness of the Carboniferous beds is about six hundred meters.

In 1918 the federal government of Brazil had a well put down in the Carboniferous beds on the headwaters of Rio Maués between Tapajos and the Canumá. It passed through limestones, shales, and sandstones, and reached a depth of 292 meters. To a depth of 217 meters several of the limestone beds contained marine Carboniferous fossils.

These Paleozoic rocks, however, are known only in the eastern end of

the State of Amazonas; they are not certainly known west of 58 degrees longitude on the south side of the valley or west of 60 degrees on the north side. Farther west the Paleozoic beds are concealed by the soft Tertiary and Quaternary deposits that cover thousands of square miles and extend westward to and beyond the Peruvian frontier. Here and there the Archean and Paleozoic beds are cut by dikes of eruptive rocks, but nowhere in the Amazonas region are the dikes known to pass through Cretaceous or Tertiary beds.

Of the area about the headwaters of the Rio Branco but little is known beyond what is to be had from the reports of Brown and Sawkins on the adjoining parts of British Guiana. The areas colored as questionable Cretaceous are merely areas of sandstone resting on the Archean. The rocks have as yet furnished no fossils.

Of the area between Rio Negro and the Amazon but little is known, further than that it is a flat, forest-covered region of sluggish streams. The country of the western end of the state is represented as Pliocene chiefly on account of the determinations of fossils by Ethridge. (See bibliography below.) The rocks are mostly incoherent sands and clays. The Miocene area, however, embraces large tracts that should properly be shown as alluvial deposits along the streams. Our knowledge of the limits of such areas is too fragmentary to allow them to be shown on the map.

Economic geology.—Gold is said to be found about the headwaters of some of the rivers of the State of Amazonas, but there is no systematic mining of any kind. Limestone is abundant in the Carboniferous rocks exposed along the rios Paranary and Amana and probably also on the Abacaxis. Similar deposits on the Jamundá and Uatuma probably contain limestones. Good clays for the manufacture of bricks, tiles, and the common ceramic ware used in the region are abundant, and the Archean region along the upper Rio Negro and Rio Branco furnishes unlimited supplies of excellent granite for building stones.

Lignite has long been known in the western part of the State of Amazonas. It occurs in the fresh-water Tertiary beds about Tabatinga on the upper Solimões, Javary, and Iça, and it probably has a wide, but uneven, distribution over an enormous area along the Peruvian frontier. Analyses show it to contain about 33 per cent of fixed carbon, about 39 per cent of volatile hydrocarbon, and 15 per cent of ash.

Geologic Maps of Amazonas

C. Barrington Brown, 1879.—The paper by C. Barrington Brown, "on the ancient river deposits of the Amazon," published in the Quarterly

Journal of the Geological Society of London, volume 35, 1879, contains a small scale map (plate 38) showing the distribution of recent alluvium and the old river deposits of the region between the Brazilian and Peruvian frontier and the mouth of the Amazon, while the character of the rocks in the adjoining areas are given and the ages of some of them are stated.

H. Karsten, 1886.—The geological sketch accompanying Karsten's "Géologie de l'ancienne Colombie bolivarienne, Venezuela, Nouvelle-Granade et Ecuador, Berlin, 1886," represents the geology of the State of Amazonas west of Manaus. The map is on a scale of 1 to about 7,418,-000, and only two geologic divisions are shown in the Brazilian area, namely, plutonic and Tertiary and Quaternary—the last two in one color.

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BAHIA

Previous investigations.—The base map of the State of Bahia has been prepared partly from the original map of Branner, Crandall, and Williams, partly from the maps of Dr. Theodoro Sampaio, and partly from those of the Inspectoria de Obras Contra as Seccas made under the direction of Dr. M. A. R. Lisboa.

The geology of Bahia as given on the map has been prepared chiefly from the author's own observations and notes, supplemented by the notes of his assistants, Roderic Crandall and Horace E. Williams. The notes on the geology made by Dr. Theodoro Sampaio on a trip from Carandahy to Bahia form a valuable contribution to our knowledge, while the notes of Sir Richard Burton and of Halfeld on the geology along the Rio São Francisco, though fragmentary, have been very helpful. The region north of Rio São Francisco was crossed by George Gardner and by J. W. Wells, who give useful notes on the geology.

The coast region is described by Rathbun on Itaparica, by Gonzaga de Campos on Marahú, by Branner on the whole coast, while the fossils are described by Jones, Krasser, C. A. White, and A. Smith Woodward.

The great Bemdigo meteorite found in the interior of Bahia and removed to Rio de Janeiro in 1888 is described by Carvalho, Daubré, and Derby.

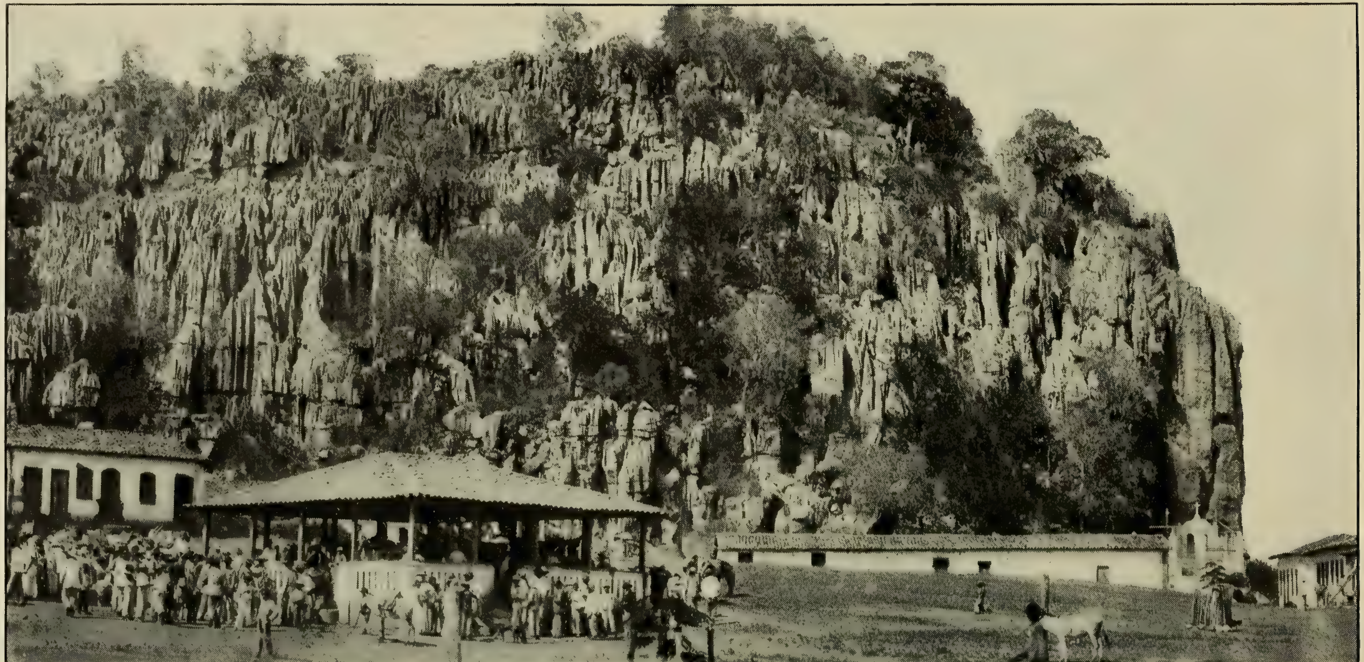
General geology.—The geology of the State of Bahia is remarkably varied and interesting. The rocks of the Brazilian complex—the Archean

FIGURE 5.—*Section 10 Kilometers long across the Serra de Jacobina at Jaguarary, State of Bahia*

The old Paleozoic beds are faulted and thrust beneath the Archean on the east. The location of the manganese beds is near east base of the mountains.

granites, gneisses, and schists—are exposed over large areas; into these oldest rocks have been faulted and folded here and there an old series of quartzites and other metamorphosed rocks that appear in the topography as isolated peaks and ridges, usually with their beds standing on end or at high angles. These rocks are shown on the map as early Paleozoic, and are typified in Bahia by the Serra de Jacobina, Serra de Angico, and by the long isolated ridges of quartzite west of Rio São Francisco between Barra and Urubú. No paleontologic evidence of the age of these beds has yet been found.

Extending along the east side of the Rio São Francisco from near



CHARACTERISTIC WEATHERING OF LIMESTONE

The limestone forms the bluff at Bom Jesus da Lapa, on the Rio São Francisco, State of Bahia. The famous chapel of Bom Jesus is in a cave beneath the bluff; the entrance is at the cross, visible at the right.

Joazeiro to the southern end of the State of Bahia, and extending into Minas beyond, is a mountainous and hilly region averaging 200 kilometers in width, mostly of Paleozoic sediments folded, faulted, and denuded. They are made up chiefly of hard quartzitic sandstones, shales, and slates covered here and there by limestones. The geologic ages of

FIGURE 6.—*East-west Section across the Serra do Tombador, the Serra de Jacobina, and the Archean Valley between*

these rocks are not certainly known; for, with the exception of certain limestones to be mentioned later, not one of them has yet yielded recognizable fossils.

The lowest rocks of this group, the Tombador beds, have been referred tentatively to the Silurian. These lowest of the sedimentary rocks form the escarpment of the Tombador range west of Jacobina, the cap rock of

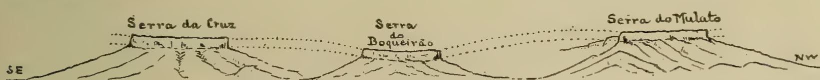


FIGURE 7.—*Structural Relations of Serra da Cruz, Serra do Boqueirão, and Serra do Mulato*

The crests are of Tombador quartzite; the slopes and plains are of old crystalline rocks.

the Serra do Mulato, Serra da Cruz, Serra do Encaibro, Serra de Macaubas, and Serra Geral on Rio São Francisco, and they generally underlie the later rocks of the diamond mining regions of the State of Bahia.

The limestones at Bom Jesus da Lapa on Rio São Francisco have been referred by Derby to the Silurian on the evidence of the fossils *Favosites*

FIGURE 8.—*Northwest-southeast Section from Rio São Francisco to the Salitre Valley, about 160 Kilometers*

The section shows the general geologic structure of the diamond region of Bahia. The Caboclo shales are exposed in the Almas Valley, with the diamond-bearing beds overlying them.

and *Chetetes* found there. This determination, however, is not to be regarded as final, for both of these fossils occur also in the Devonian, and the *Chetetes* is even found in the Carboniferous.

Next above the Tombador beds is a series of slaty shales well exposed in the Almas Valley, and called the "Caboclo shales" for the Caboclo peak

on the east side of the Almas Valley. These shales have been referred to the Devonian, but without paleontologic evidence.

Resting on the Caboclo shales are the Lavras quartzites and sandstones from which the diamonds and carbonados are obtained in the State of Bahia. These quartzites and sandstones are sometimes yellowish brown, white, or gray, but they are more frequently pinkish and are almost everywhere strongly false-bedded. Over most of the area they are folded, and in some places they are much faulted. They are represented on the map as doubtful Carboniferous, for here again no paleontologic evidence has yet been found of their age.

The Lavras beds have a total thickness of two hundred to two hundred and fifty meters near Lençoes. (Crandall.)

I am of the opinion that the Lavras quartzites of Bahia are to be correlated with the diamond-bearing quartzites of Grão Mogol, in the State of Minas Geraes. Unfortunately the structural connection between the two regions has never been worked out. See also page 265.

Overlying the diamond-bearing quartzites of the *Chapada diamantina* is a series of limestones with interbedded shales that I have hitherto referred with doubt to the Jurassic and Triassic.[46] The accumulated evidence leads me to conclude that the limestones called by me the Salitre are simply the northward extension of the Lower Permian limestones of the Rio das Velhas, Rio Verde, and of the upper Rio São Francisco.

The maximum thickness of these limestones in Bahia is not known, but it is at least 100 meters. They are mostly horizontal and thin bedded, but in some places they are highly folded. It is not at all improbable that there are limestones in the *Chapada diamantina* older than the Permian, but data for distinguishing them are entirely lacking at present.

At Jacú, a few kilometers east of the town of Aracy, which is 40 kilometers north of Serrinha, a station on the Bahia São Francisco Railway, fossils of Permian age have been found in dark gray shales. Permian

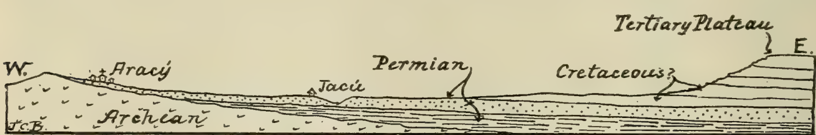


FIGURE 9.—*Section from the Archean near Aracy to the Tertiary Table-lands to the East*

fossils have also been found 12 kilometers south of the town of Bom Conselho, in eastern Bahia. The Permian beds at these two places underlie the tablelands that form the belt shown on the map as Cretaceous and

[46] Am. Jour. Sci., vol. xxxi, p. 481. Bul. Geol. Soc. Amer., vol. 22, p. 188.

Tertiary and which extends from the vicinity of the city of Bahia to and across the Rio São Francisco above the falls of Paulo Affonso. The Permian rocks have not been recognized as such elsewhere throughout this entire zone, but it is assumed that they are continuous, and they are so represented on the map. Nowhere else in Bahia have the Permian rocks been certainly recognized.

In the Salitre Valley and over wide areas in the country north of Lavras the map shows limestones which are referred doubtfully to the Permian. These limestones have yielded no fossils, with the possible exception of some algæ that have thus far baffled all attempts at determination. The age of the beds is therefore in doubt. In some places they seem to rest unconformably against the diamond-bearing quartzites referred to the Carboniferous. It is not at all clear, however, that these limestones are all of the same geologic age.

Cretaceous rocks are exposed at many places about the Bay of Bahia, on the east side of the island of Itaparica, at Marahú, and at many places through the zone of sedimentary rocks that extends from Bahia northward to near Jatobá, on the Rio São Francisco. At Marahú and about the Bay of Todos os Santos fossils have been found, and there is no question about the age of certain rocks. All of the sedimentary rocks thereabout are not Cretaceous, however, as seems to be inferred occasionally, for there are at many places remnants of the Tertiary beds, most of which have been completely removed by denudation. On the island of Itaparica Dr. Rathbun recognized Tertiary beds on the west side of the island; at Monserrate, in the suburbs of Bahia, brackish water fossils are found that are certainly Tertiary,[47] and in some of the railway cuts northwest of Alagoinhas Tertiary plant remains are abundant in sediments overlying unconformably the Cretaceous beds[48] at kilometer 28+.

Any one who undertakes geologic or paleontologic work in the vicinity of the Bay of Bahia should not fail to read the paper by Joseph Mawson published in the Geological Magazine of August, 1913, pages 356-361. Mr. Mawson lived at Bahia many years, and it is to him that we owe the valuable collections of Cretaceous vertebrate remains described by Dr. A. Smith Woodward.

Along the coast, both north and south of Bahia, is a narrow belt of Tertiary sediments that lap back over the older formations. This belt is cut through here and there by the drainage, and where the sea has undercut the beds they form the particolored cliffs that characterize this part

[47] See Chas. A. White's Contributions to the Paleontology of Brazil. Archivos do Museu Nacional, vii, p. 233.

[48] F. Krasser: K. von. Ettingshausen's Studien uber die fossile flora von Ouricanga in Brasilien. Sitz. der K. Akad. d. Wiss. Wien., cxii, 1903.

of the Brazilian coast. The Tertiary beds are mostly horizontal sands and clays.

In some parts of the interior of Bahia ant-hills of enormous size cover the surface of the ground so completely that they seriously interfere with its cultivation and produce a peculiar and striking minor topography.

Economic geology.—The minerals and rocks of economic importance in the State of Bahia are gold, diamonds, carbonados, amethysts, monazite sands, manganese, bituminous shales, marbles, limestones, and pottery clays. These materials have all been worked in Bahia except possibly

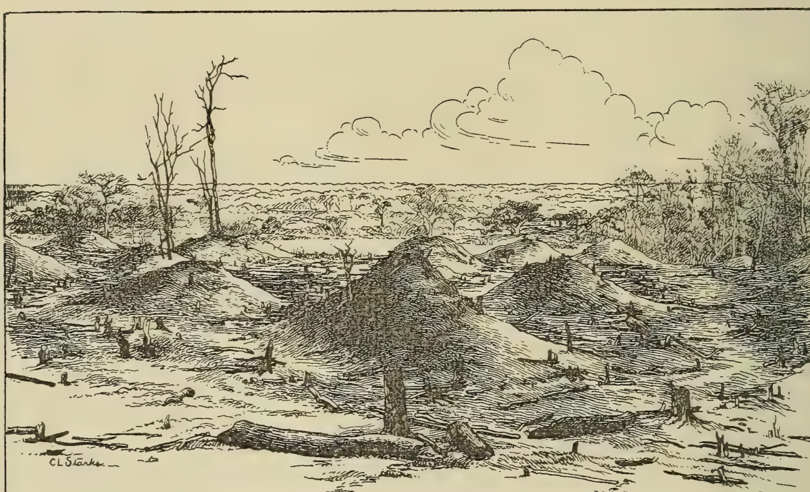


FIGURE 10.—*Ant-hills on Rio Utinga*

The view is taken near the village of Pegas, State of Bahia. From a photograph by R. Crandall, 1907.

the marbles. Bituminous shales were worked at Marahú for a while, but the enterprise was soon abandoned. There are, however, other mineral resources in the state that have not yet been developed; such are iron, considerable bodies of which occur below Chique-Chique; copper, found at Carahyba; mica, talc, graphite, grindstones, whetstones. Nitrate of potash and salt are found in the interior of the state, but the nitrate occurs only as cave deposits, while the salt is manufactured by leaching the surface earth from dry lake beds, mostly in or near the limestone areas. The limestones and clays so abundant in the state might be used for the manufacture of Portland cement, but they have never been utilized.

Those who seek information in regard to the geology of the diamond

and carbonado regions should consult the papers of Branner, Derby, Crandall, Furniss, Gorceix, and Oliveira.

The monazite sands are described in a résumé by Dr. Calogeras in his "Minas do Brasil e sua legislação," pages 447-477. Other writers on monazite sands are Derby, Gorceix, Praguer, and Britto. The manganese deposits are spoken of by Branner and are mentioned under "Monazite" above.

Geologic Maps of Bahia

Pissis, 1842.—In his Mémoire sur la position géologique des terrains de la partie australe du Brésil, par M. A. Pissis, published by the Academy of Sciences at Paris in 1842, the accompanying geologic map includes the geology of the southern part of the State of Bahia. Four divisions of the "terrain primitif" are shown. The map shows evidences of some work at and south of the Bay of Bahia.

Branner, Crandall, and Williams, 1908.—A map showing the geology of that part of the State of Bahia lying south of Rio São Francisco, east of west longitude 43° and north of latitude 12° 30′ was published by the Inspectoria de Obras Contra as Seccas in 1908, under the title "Mappa de parte dos estados da Bahia, Pernambuco e Piauhy e dos estados de Sergipe e Alagoas por J. C. Branner, R. Crandall, e H. E. Williams." It was originally prepared for the Serviço Geologico e Mineralogico do Brasil, but it was only issued as stated above. It is on a scale of 1 to 2,000,000 and shows six geologic subdivisions: crystallines, Jacobina series, Tombador series, Lavras series, Salitre series, and recent Tertiary and Cretaceous—the last three in one color. This map is not accompanied by any text.

Branner, 1909.—A short article by Branner on "the diamond-bearing highlands of Bahia," published in the Engineering and Mining Journal, New York, May 15 and 22, 1909, was accompanied by a geological sketch-map of the region between the city of Bahia and Chique-Chique, on the Rio São Francisco. The scale was 1 to 3,030,303 and four geologic divisions were shown, namely: crystalline, Lavras, Salitre limestone, Cretaceous and Tertiary—the last two as one. The geology on that map was based almost exclusively on observations made by the author and his assistants.

Soper, 1914.—In 1914 the eastern part of the State of Bahia was shown on a map accompanying the report of R. H. Soper to the Inspectoria de Obras Contra as Seccas. This was publication number 34 of the Inspectoria, and has the title "Geologia e supprimento d'agua subterrenea em Sergipe e no nordeste da Bahia." The map is on a scale of 1

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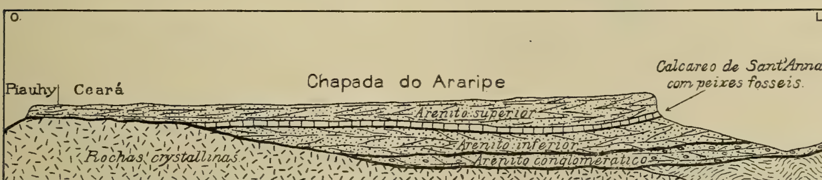
CEARÁ

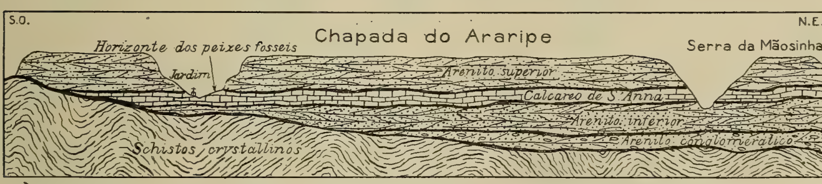
Previous investigations.—The base map of Ceará is copied from the map of that State made by the Inspectoria de Obras Contra as Seccas under the direction of Dr. M. Arrojado R. Lisboa.

Fairly comprehensive reports have been made of late years on the general geology of Ceará by Crandall, Small, Waring, and Soper. Earlier valuable notes are those of Capanema, George Gardner, Pompeu de Souza, and Spix and Martius. The noted Cretaceous fossil fishes are described by L. Agassiz, and lately Dr. D. S. Jordan has prepared a full report on them for the Serviço Geologico do Brasil. The report has not yet been published.

General geology.—The surface rocks over most of the State of Ceará are the granites, gneisses, and schists of the Brazilian complex. Along the western frontier the Serra Grande mountain range is of sedimentary rocks that have been called lower Permian by Small and Cretaceous by Crandall. The Araripe range, which lies along the southern boundary, is Cretaceous, while the entire coast is bordered by a narrow belt of Tertiary sediments. The Archean of Ceará is cut at many places by intrusives, and faults have let down into the granites and gneisses the ends of some of the old sedimentary beds that now appear in the topography as ridges of quartzites. A typical instance of this structure is shown in the



Secção geologica mostrando a estructrua da Chapada do Araripe.
Conforme H. L. Small.



Secção geologica da Chapada do Araripe entre Serra da Mãosinha e Jardim.
Conforme H. L. Small.

FIGURE 11.—*Two Sections showing the geologic Structure of the Chapada do Araripe, in southern Ceará*

The fossil fishes are from the Sant'Anna limestone.—H. L. Small.

Serra de Tucunduba, whose geology is given in the report of H. L. Small opposite page 46. There are also a few isolated infolded or infaulted fragments of some of the newer rocks scattered over the Archean area.

The Lower Permian—the "Serra Grande series" of Small—forms the eastern escarpment of the Serra Grande, a range of mountains on the western frontier, extending from near the ocean on the north to seven degrees south latitude, nearly to the Serra do Araripe. The rocks of the Serra Grande are coarse calcareous sandstones, limestones, and conglomerates, usually false-bedded, and having a maximum thickness of 700 meters just west of the town of Ipú. For the most part the dip of these beds is from four to seven degrees toward the west or northwest. No fossils have been found in the Serra Grande rocks, and the age of the

series is not certainly known. They are referred tentatively to the lower Permian by Mr. Small, chiefly because beds known to be Permian overlie them on the west. There are several outliers, supposed to be of the same age as the Serra Grande rocks, at and north of Serra da Rola on Rio Acarahú. The rocks of the Serra da Rola itself dip northward, and several kilometers down the river the dip is to the south. There are a good

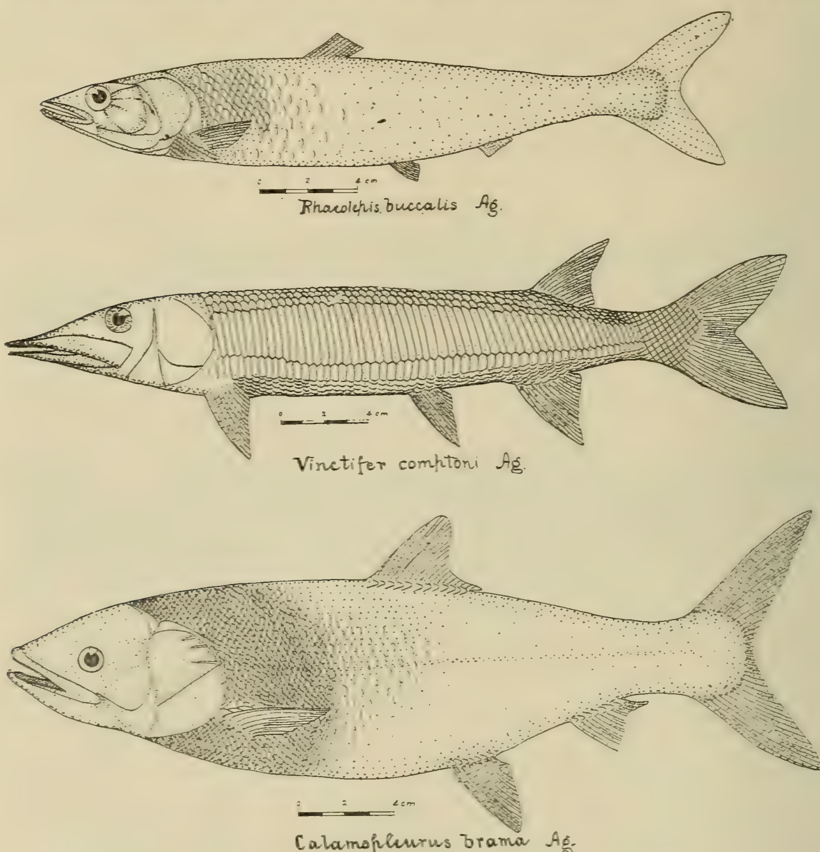


FIGURE 12.—*Cretaceous Fishes from the Serra do Araripe*
Restored by D. S. Jordan.

many caves in the limestones of the Serra Grande series, the best known of which is the Gruta de Ubajárra, 13 kilometers northeast of Itiapina.

The Serra or Chapada do Araripe, on the southern frontier of Ceará, is a flat-topped tableland of nearly horizontal Cretaceous rocks. The two accompanying sections by Small show the general features of the geology and dispense with the necessity of further description. In the bed called

the "Sant'Anna limestone" fossil fishes are found that show satisfactorily the Cretaceous age of this series.

The irregular zone of coastal sediments shown on the map as Pliocene extends along the entire coast and varies in width from 5 to 35 kilometers. The rocks are mostly soft reddish, yellow, and mottled sandstones and clays in which no fossils have yet been found in Ceará. The Tertiary beds all dip gently toward the ocean. Some of the beds contain much iron locally. They are assumed to be Pliocene because there is a lower series at Mossoró known to be Eocene. The thickness of these sediments varies greatly, but in the State of Ceará they probably do not exceed 50 meters.

At a few places along the coast, notably at Canoa Quebrada, near Aracaty, are short sandstone reefs of Quaternary age, similar to those at Natal and Pernambuco.

Economic geology.—Gold has been washed at many places, but I know of no gold mine now in operation in the state. Iron is abundant at many places, both in the old crystalline series and in later deposits, but it is not mined, and no systematic search has been made for ore bodies worth working. Copper in the form of the carbonate is known at Fazenda Pedra Verde seven kilometers northeast of Viçosa. The deposit is described in Small's report, at page 141. Bituminous shales are found in the Cretaceous rocks of the Serra do Araripe. Books and articles on the state give long lists of minerals found there, but it is not claimed that they are sufficiently abundant to warrant exploitation. White crystalline marble occurs at several places in the interior, and ordinary limestone is abundant along the eastern flank of Serra Grande and in the Serra do Araripe, in the southern end of the state. As the state suffers much from long periodic drouths, subterranean water supply is of great importance in Ceará. Such water is found most certainly in the coastal sediments, though it is occasionally found in small quantities in the Archean area. Data collected by Small show that out of sixty-one wells sunk in the sedimentary beds along the coast 77 per cent yielded fairly good water, while out of twenty-three wells sunk in granites, gneisses, or schists 45 per cent only yielded fairly good water (Small, page 56).

Geologic Maps of Ceará

Crandall and Williams.—In 1910 the "Inspectoria de Obras Contra as Seccas" published a geologic map of the States of Ceará, Rio Grande do Norte, and Parahyba. The authors of the map were Roderic Crandall and H. E. Williams, both, at that time, assistants on the Serviço Geologico e Mineralogico do Brasil. The map was on a scale of 1 to 3,000,000

and five divisions of the geologic column were represented, namely: (1) granites, (2) gneisses and crystalline schists, (3) the Ceará series, which is not well defined, but seems to belong with the gneisses and schists; (4) Cretaceous, and (5) Quaternary. This map is called Publication number 7, Series I, G of the Inspectoria de Obras Contra as Seccas. It was not accompanied by text, but Mr. Crandall's report on the geology of that region, published by the Inspectoria as number 4, Series I, D, E, may be accepted as the text.

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ESPIRITO SANTO

Previous investigations.—The geology as shown on the map is largely from the personal observations of the author. Publications regarding the geology of the state are limited almost entirely to the notes of Hartt, two short papers by Freise, and the very few notes by Maximilian Wied-Neuwied. Auguste St. Hilaire, the French botanist, crossed the state, but he has very little to say about the geology.

General geology.—The general geology of the State of Espirito Santo is quite simple: Archean gneisses, granites, and schists form the mountains and high western part of the State and of most of the interior; Pliocene (?) and later sediments form a belt along the coast and lap back over and against the Archean rocks. Little is known of the details of the geology of the State, but it is probable that quartzites and old metamorphic rocks are here and there let down into the older masses by faulting.

There are two and possibly three divisions of the coastal sediments: an older, basal division, in which no fossils have yet been found, and a later division, of soft and incoherent yellow sands and clays, blackened here and there by iron or vegetable matter or bleached by acidulated waters, containing marine fossils, separated from the older division by an unconformity.

These Tertiary beds all dip gently toward the ocean. They probably do not exceed fifty meters in thickness, and are cut entirely through along

Rio Mucury and in Lagoa Juparanã, where the underlying granite is exposed.

The Tertiary belt is about eighty kilometers wide at São Matheus, near the north end of the state, and narrows to a width of about twenty kilometers at the south end, while at several points between, notably at Benevente and at Victoria, these Tertiary sediments have been completely removed by denudation.

About the mouth of Rio Doce is a large area of swampy lands that should probably be regarded as recent alluvial deposits rather than Pliocene.

Economic geology.—But little is known of the mineral resources of the State of Espirito Santo. Rocks of the Brazilian complex cover most of the State, and within that area many of the minerals common to Brazil have been found. Friese reports finding wolframite in the Serra dos Aymores north of the Rio Doce. Monazite sands are found along certain parts of the sea beaches north of Victoria. Limestones (probably marbles) are said to cover a considerable area in the Valley of Rio Castello.

Geologic Map of Espirito Santo

Pissis, 1842.—The map accompanying the Mémoire sur la position géologique des terraines de la partie australe du Brésil, par M. A. Pissis, Paris, 1842, includes the geology of the entire State of Espirito Santo. The map is on a scale of 1 to 2,500,000, but it does not show evidences of much work done in the State of Espirito Santo.

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all that was translated and includes volume I of the French edition and chapter XI of volume II, up to page 206.)

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GOYAZ

Previous investigations.—The base map of Goyaz is made up partly from the coordinates along the Rio Araguaya by Dr. W. Berky for the Department of Terrestrial Magnetism of the Carnegie Institution and partly from the map of the Commissão de estado da Nova Capital da União, under Dr. L. Cruls, Rio, 1896.

The location of the Tocantins and the Paranãn is taken from the Brazilian government's map of the prolongation of the Estrada de Ferro Central do Brasil do Rio a Belem, 1917.

The report of the expedition of Castelnau across Goyaz and of his trips on the Araguaya and Tocantins contains many notes on the geology, though it is often difficult to locate the places mentioned. George Gardner's travels and Pohl's Gebirgskunde Brasilien are also very helpful.

The report of Cruls on the Planalto Central do Brazil has important notes on the mineralogy, and on the geologic structure, by Hussak.

In the northwest corner of Goyaz, where it touches the State of Pará, I have felt obliged to omit the Cretaceous beds along the Araguaya, as shown by Katzer in his map of the geology of Pará.

General geology.—The Archean rocks in the State of Goyaz extend from Rio Parnahyba, southwest of Santa Rita do Parnahyba, and from south of Catalão northward past Bella Vista, Pyrenopolis, and the city of Goyaz to Porto Nacional, on the Rio Tocantins—a distance of more than eight hundred kilometers. This Archean belt has a width of four hundred or five hundred kilometers, more or less. The details of the outlines of the area shown on the map, however, make no claim to accuracy, while the limits of the Archean along the western side of the state are almost entirely unknown. There are a few small Archean areas exposed where the overlying rocks have been removed by denudation. One of these is reported by Gardner at Natividade. There appear to be areas of infaulted old Paleozoic rocks within the area of Archean rocks in the region about the city of Goyaz and elsewhere, but, for lack of a knowledge of details, it is quite impossible to outline any of them at present.

There seems to be an area of old Paleozoic rocks about the headwaters of Rio Araguaya, but very little is known either of the character of the

rocks or of the area covered by them. Castelnau speaks of them as much contorted argillaceous schists dipping south and southeast.[49]

The summit of the divide in the new federal district northeast of Pyrenopolis and west of Formosa is capped by sedimentary rocks that I have referred provisionally to the Upper Permian. These rocks extend southward along the divide between Rio São Marcos and Rio São Bartholomeo and appear to connect with the Upper Permian in Minas Geraes near Patrocinio. To the north of Formosa these same sedimentary beds form the great plateau along the watershed to the north, between the States of Goyaz and Bahia, to and beyond the frontier with Maranhão and Piauhy.

In the vicinity of Pyrenopolis these Permian sediments are a mere remnant, but farther north they spread out until they have a width of 600 kilometers or more in the northern part of the State of Goyaz.

The notes of George Gardner show that the rocks are about horizontal, and that they are mostly sandstones and limestones.

Inasmuch as there are cavernous limestones in the Serra do Roncador in northeast Matto Grosso, it seems probable that these beds extend quite across northern Goyaz into the States of Pará and Matto Grosso.

The map shows an area of Triassic rocks in the southwestern part of the State of Goyaz. Triassic rocks are known in the adjoining States of São Paulo and Minas Geraes, and it is inferred that the similar beds on the northwest side of Rio Paranagua are also Triassic. The precise locations of the margins of the Triassic rocks in the State of Goyaz, however, are not known at present.

Overlying the Triassic rocks in the southwest corner of the State is a later series of sediments supposed to be of Cretaceous age. The only notes we have of this series are those of Castelnau, who crossed them on the road leading from Goyaz to Cuyabá, in the State of Matto Grosso. The drawings and photographs given by Henry Savage-Landor at pages 253, 256, and 352 of his "Across Unknown South America," Boston, 1913, give a vivid idea of the topography and structure.[50]

Economic geology.—Goyaz has produced notable quantities of gold, chiefly from placer deposits where it is derived from schists. Diamonds and other precious stones have also been mined, especially along Rio Claro, an affluent of the upper Rio Araguaya. Iron, both magnetic ore and hematite, is reported from many places in the State, but very little is known as yet about the quantity available. Hussak mentions one bed,

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[49] Expedition . . . histoire du voyage, vol. ii, p. 248. Paris, 1850.

[50] Unfortunately that author's statements about lavas are not to be trusted. The rock so named by him is mostly the well known *canga* or limonite iron ore, while the "lava over giant volcanic dome" at page 270 is an exfoliated mass of sandstone.

30 meters thick, near Meia Ponte (now called Pyrenopolis). Dr. Lisboa mentions the occurrence of bituminous and gypsiferous shales at the confluence of Rio Sereno with Rio Manoel Grande in the Tocantins lowlands.[51]

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[51] American Journal of Science, May, 1914, vol. xxxvii, p. 439.

MARANHÃO

Previous investigations.—In the preparation of the geographic base for the State of Maranhão I have had the benefit of the coordinates determined by Dr. Arnaldo Pimenta da Cunha and published in the Boletim Official do Ministerio da Industria, Viação e Obras Publicas, 1° anno, tomo II, page 158, Rio de Janeiro, 1909.

The most valuable papers on the geology of Maranhão are those of Dr. M. Arrojado R. Lisboa, the notes of Spix and Martius, and those of James W. Wells. The interior of the state is but little explored. On the lower Tocantins I have followed Castelnau by referring his sandstones and shales to the Permian of Lisboa.

General geology.—Archean rocks are known in Maranhão along Rio Gurupy, on the lower portion of the Tury-assu, and along a short piece of Rio Itapicuru between Codó and Coroatá. It is possible that there is also a belt of Archean exposed along Rio Grajahú near four degrees south latitude, where Wells reports a hard dark "greenstone" very similar to that at Chapada.[52]

The oldest known rocks in Maranhão after the Archean are supposed to be the Permian sediments, which cover nearly half of the state. These Permian beds, as described by Dr. Lisboa, are here mentioned in their natural order:

Unconformity at the Top of the Permian

	Thickness in meters
7. Green and chocolate-colored shales, limestones, and white sandstones.	3
6. São Bartholomeu sandstone, ashen gray, false-bedded................	50
5. Pisolitic rock, mostly white sandstone............................	?
4. Jaboti red sandstone, with purple spots...........................	±150
3. Mendes sandstone, ashen gray to white.............................	?
2. Ashen gray marly shales and calcareous beds........................	?
(Interval not seen.)	
1. Bituminous shales.	

These sedimentary beds are nearly horizontal, and are cut here and there by dikes and interstratified with sheets of diabase.

Next above the Permian beds is the Mearim series of Lisboa, and provisionally referred by him to the Triassic. These beds are principally red sandstones having a thickness of 100 meters. In places they contain flows of amygdaloidal trap.

In the Serra Vermelha above the city of Grajahú these beds dip locally west-northwest, and the red sandstone, with the included trap, has a thickness of 235 meters.

[52] J. W. Wells: Three thousand miles through Brazil, vol. ii, p. 291. London, 1886.

A soft yellow sandstone that overlies the Triassic and forms the top of the plateau of Grajahú is referred by Lisboa to the Cretaceous. In places these sediments are argillaceous; the whole series dips gently toward the coast.

Along the coast of Maranhão is the Tertiary zone characteristic of the coast of northern Brazil. These beds are horizontal sediments, here and there cemented with iron. Where the sea is encroaching on them they form bluffs, and where the sands are encroaching on the sea the coast is low and the hard rocks are covered by sand-dunes.

It was formerly supposed that the marine fossils found at Pirábas, on the coast of Pará, were Cretaceous, and they were therefore included in Dr. C. A. White's description of the Cretaceous fossils of Brazil. Later studies have shown that those fossils are Eocene.[52] Reference is here made to the Pirábas fossils because Dr. Lisboa found at Carutapera, in the northwest corner of Maranhão, fossiliferous limestone "with a fauna similar to that of Pirábas." The Carutapera region is therefore to be classified as Eocene unless a fuller study of the fossils found there should warrant a different conclusion.

Economic geology.—But few minerals of economic importance are certainly known in the State of Maranhão. Some gold has been mined; bauxite is reported in the sedimentary beds of the west, and Dr. Lisboa found bituminous shales near Codó and at several other places in the state. Burlamaqui reports such shales on Rio Mearim near Barra do Corda. Limestone, probably of Permian age, is abundant on Rio Grajahú, where it has a thickness of 25 meters. Iron has long been reported from the island of S. Luiz, but there is no information available regarding the quantity and quality of the ore.

Geologic Map of Maranhão

Lisboa, 1914.—Dr. M. A. R. Lisboa published, in the American Journal of Science for May, 1914 (volume 187, pages 425-443), an article on the Permian geology of northern Brazil, and accompanying it was a small map showing the geology of a large part of the State of Maranhão. It is on a scale of 1 to 1,126,760, and four geologic divisions are represented, namely: crystalline, Permian, Triassic, and Cretaceous.

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[52] Carlotta Joaquina Maury: A contribution to the paleontology of Trinidad. Jour. Acad. Nat. Sci. of Philadelphia, vol. xv, pp. 32-33. Philadelphia, 1912.

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MATTO GROSSO

Previous investigations.—The base map of Matto Grosso is made up chiefly from the following data:

1. Locations along Rios Guaporé and Madeira by R. H. Schmidt, of the Department of Terrestrial Magnetism, Carnegie Institution.

2. Rios Gy-Paraná, Theodoro, and the Tapajos are copied from the map given in the lectures of Colonel Candido Mariano da Silva Rondon, published at Rio de Janeiro in 1916.

3. Rio Xingú is from the maps of Karl Von den Steinen's Erforschung des Xingú.

4. The southern part of the State is from Schnoor's map, given in Dr. M. A. R. Lisboa's paper in "Oeste de São Paulo, Sul de Matto Grosso. Geologia," etcetera. Rio de Janeiro, 1909.

Castelnau gives the geology along the routes followed by his expeditions from Goyaz to Cuyabá and thence to Villa Bella. Evans' paper on the region northwest of Cuyabá is valuable; the geologic notes on the Xingú by Dr. Vogel and by Clauss and the occasional notes given by J. S. da Fonseca are helpful.

The notes of Euzebio Paulo de Oliveira on the "Expedição Roosevelt-Rondon" and those of Alberto B. Paes Leme after the notes of Cicero de Campos are most welcome additions. The most valuable late contribution to the general geology of Matto Grosso is by Dr. M. Arrojado R. Lisboa, who crossed the southern end of the state from São Paulo to Curumbá, along the line of the new railway route.

The best general description of the state is that by Herbert H. Smith.

On the paleontology Clarke, Knod, and Von Ammon are most important.

General geology.—Geologically Matto Grosso is the most interesting and the least known of the Brazilian states. The available notes and

observations on its many geologic problems are unusually difficult to harmonize, and the results as shown on the map must not be regarded as anything more than an effort to bring them into accord with each other and with what is known of the geology of adjoining regions. The few notes I have been able to find on the geology along the Rio Guaporé are by Dr. João Severiano da Fonseca.[53] The geology along the Gy-Paraná and the Rio Theodoro is chiefly from the notes and reports of Euzebio Paulo de Oliveira.[54] The general geology of the Serra do Norte and of the plateau west of Diamantino is also chiefly from his paper.

The Parecis sediments (Cretaceous?) are shown on the map as crossing Rio Tapajos about seven degrees south latitude, in accordance with the notes of Chandless.[55] On the upper Xingú we have a very few notes in the papers of Dr. P. Vogel[56] and of Otto Clauss.[57] The Parecis sandstone of the plateau is referred provisionally to the Cretaceous, in accordance with the suggestion of Euzebio Paulo de Oliveira, though, as he points out, no fossils characteristic of that age have yet been identified from that series.[58] This agrees also with an earlier suggestion of Derby, made in 1895 and based on vertebrate remains found in the horizontal sandstones north of the Chapada.[59]

The geology of the southwestern part of the state is chiefly from the report of Dr. M. A. R. Lisboa.[60] Some light is to be had on that part of the state, however, from what has been published on the geology of Paraguay. Near Villa Rica *Stereosternum tumidum*,[61] a fossil characteristic of the Upper Permian of Brazil, has been found, while in the mountains of northeastern Paraguay have been found *Productus* and *Spirifer poststriatus*, fossils characteristic of the Permian.[62] These fossils suggest the possibility of the "Bodoquena" of Dr. Lisboa being Permian, in part at least.[63]

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[53] Viagem ao redor do Brazil, vol. ii. Rio de Janeiro, 1881.

[54] Reconhecimento geologico do Noroeste de Matto Grosso.

[55] W. Chandless: Notes on the rivers Arinos, Juruema, and Tapajos. Journal Royal Geographical Society, vol. xxxii, pp. 268-280. London, 1862.

[56] P. Vogel: Reise in Matto Grosso, 1887-8. Zeit. der Gessellschaft für Erdkunde zu Berlin, xxviii, Berlin, 1893; also in Von den Steinen's Erforschung des Xingu: durch Zentral-Brasilien, Leipzig, 1886.

[57] Otto Clauss: Bericht über die Schingu-Expedition, 1884. Petermann's Mittheil., vol. 32, 1886, pp. 129-134, 162-168.

[58] Expedição scientifica Roosevelt-Rondon. Annexo no. 1 Geologia, pp. 33, 76. Rio de Janeiro, 1915.

[59] Archivos do Museu Nacional, vol. ix, p. 63. Rio de Janeiro, 1895.

[60] Oeste de São Paulo, Sul de Matto Grosso. Geologia, etc. Rio de Janeiro, 1909.

[61] F. Frech: Lethea Geognostica, Th. i, 2 Bd., Lief 3, p. 460.

[62] Jos. v. Siemiradski: Geologische Reisebeobachtungen in Südbrasilien. Sitz. Akad. Wiss. Wien, vol. cvii, January, 1898, pp. 38-39.

[63] This is still further strengthened by a report of fossil ferns said to have been found near Miranda by Lloyd and cited by Evans. Quarterly Journal of the Geological Society of London, p. 97. London, 1894. This announcement seems to have been discredited, and I have not yet been able to verify the statement.

The northeast corner of Matto Grosso, where it joins Pará and Goyaz, has not been explored geologically. Katzer represents the adjoining part of the State of Pará as Cretaceous, but I do not find that any work has been done in that area. Paul Fountain, who traveled in the Xingú basin and along Rio Fresco and in the mountains east of there, reports in those mountains extensive caverns with abundant stalactites.[64] Of course, the limestones might be of any age from Archean to Cretaceous, but, in the absence of data to the contrary, it seems reasonable to suppose that they are of the same age as the Permian limestones east of the Tocantins, and I have therefore so represented them, subject to correction.

The foothills east of the great marshes of the Paraguay, north of Aquidauana, past Coxim, and northward nearly to 15 degrees south latitude, Dr. Lisboa marked on his map as Mesozoic with a question.[65] No fossils have been reported from these beds, but I have referred the rocks of this area to the Triassic partly because such reference fits in with what is known of the geology of São Paulo. The part of this zone between Cuyabá and Coxim was crossed by Dr. Vogel, who says the rocks are mostly red sandstones. It is also evident from Castelnau's description that there is a marked change in the topography and the geology where the road from Goyaz to Cuyabá descends from the Matto Grosso plateau at Rio Agua Branca close to 54 degrees west longitude.

The Devonian age of certain beds in the mountains east of Cuyabá has long been known. Vogel was one of those who contributed to our knowledge of that region. In his notes on the geology of the area southeast of Cuyabá he says that certain rocks are similar to the fossil-bearing beds of Taquarassú (Taquarasinhas?), and these last are Devonian beyond question. I have therefore placed in the Devonian the area south of the Chapada as far as Rio São Lourenço.[66] The dip of the rocks in the Chapada seems to carry the sandstones beneath the black shales called by Evans the "Matto shales," and these black shales underlie the sandstones of the Serra dos Parecis. It seems possible, therefore, that the shales belong to and form the upper part of the Devonian, much as the Ponta Grossa shales of Paraná overlie the sandstones. I have therefore so placed them provisionally until the question of their age can be more definitely determined. I do not overlook the views of Euzebio Paulo de Oliveira that they may be Permian—views well worthy of serious con-

[64] Paul Fountain: The River Amazon from its sources to the sea. New York, 1914, pp. 212 and 249-251.

[65] M. A. R. Lisboa: Oeste de São Paulo, Sul de Matto Grosso, Geologia, etc. Rio de Janeiro, 1909.

[66] P. Vogel: Reise in Matto Grosso, 1887-8. Zeit. der Gessell. f. Erdkunde zu Berlin, vol. xxviii, 1893, p. 274.

sideration.[67] The rocks about Cuyabá underlie the Devonian sandstones of the Chapada and were called the Cuyabá slates by Evans. I have personally examined this series at and about Cuyabá and in the region between Cuyabá and Diamantino. I was unable to find any fossils in them in the short time I could give to the work, but inasmuch as the Chapada Devonian beds rest unconformably on them, it is quite evident that they are older than the Devonian and that they are clearly separated from it. I have therefore referred them tentatively to the Silurian, including in this division both the slates exposed at Cuyabá and the zone of folded sediments described by Cicero de Campos as being near São Luiz de Caceres, and by Evans between Livramento on Rio Cuyabá and Barra dos Bugres on Rio Paraguay, and seen by me where it is crossed by the road between Rosario and Diamantino.[68]

The area called older Paleozoic, about the headwaters of Rio Alto Araguaya, in the eastern part of Matto Grosso, is known only from the few notes of Castelnau and Pohl, and those are too brief to be of much service.

That the higher portions of the region between Cuyabá and Rio Paranahyba is Cretaceous is inferred from the following:

1. In São Paulo the Cretaceous overlies the Triassic and forms the hilltops.

2. Dr. Lisboa found outliers of Cretaceous along the railway route between Itapúra and Aquidauana.[69]

3. Castelnau's description of the route between Goyaz and Cuyabá shows the Matto Grosso plateau to be of horizontal red sediments, which begin at Serra do Taquara on the east and end abruptly at Serra da Agua Branca on the west.[70]

4. The reference of these beds to the Cretaceous is in keeping with the supposed Cretaceous age of the Parecis sediments.

In a preliminary report by Dr. Lisboa on the manganese and iron mines of Urucum, in the State of Matto Grosso, and dated March, 1918, he gives the following table as the expression of his own views and those of Euzebio de Oliveira in regard to the sequence of the rocks in that state:

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[67] Reconhecimento geologico do Noroeste de Matto Grosso, pp. 74-75. Rio de Janeiro, 1915.

[68] Both Silurian and Devonian are found at Sucre, Bolivia, west of Cuyabá. See Hoek and Steinmann. Pet. Mitt., 1906. I.

[69] Oeste de São Paulo e Sul de Matto Grosso, mappa.

[70] F. de Castelnau: Expédition dans . . . l'Amérique du Sud, Histoire du Voyage, vol. ii, pp. 262-265. Paris, 1850.

Synopsis of geologic Succession in the State of Matto Grosso

By Arrojado Lisboa and E. de Oliveira, 1907-1915

		Rocks	Meters	Localities
Quaternary		Canga, alluvium.		Pantanal, Sepotuba, Taruman, Serra do Norte.
Cretaceous		Parecis sandstone	350	Serra do Norte, Parecis.
		Baurú sandstone	50	Mutum, Jacy, Cambembe. Monjolo. E. F. Burity e Branco.
Triassic	Maracajú	Paraná trapp.		Maracajú, Rio Pardo, Planalto Serra Tapirapoan, Matta da Poaia, Campos Cerrados do Sul de Matto Grosso. Aquidauana (Rio e serra) Cachoeira, Correntes e Pachechi.
		Botucatú sandstone.		
		Aquidauana sandstone	140	
Post-Permian		Nephalinic eruptives.		Pão d'Assucar, Fecho dos Morros.
Permian		Sepotuba shales and conglomerates.		Corredeiras do Sepotuba, Rio Taruman, Base da Serra de Tapirapoan, Correntes.
Devonian	Chapada	Shales and sandstones	20	Borda da Serra no districto da Chapada.
		Argillaceous shales	20	
		Arenaceous clay	10	
		Pink sandstone	100	
		Conglomerate	5	
Pre-Devonian	Jacadigo	Ferriferous conglomerate, sandstone with Fe. and Mn.	500	Urucum, Jacadigo e Risama Polvorina.
		Urucum sandstone	250	
	Bodoquena	Corumbá limestone, shales, and marls.		Bodoquena.
	Cuyabá	Cuyabá slates, hydromica schists, quartzites.		Cacipó, Cuyabá, Miranda, Rios Commemoração e Pimenta Bueno, Aquidauana e Apa.
Crystalline		Gneiss, granite, porphyry, augite, syenite.		Madeira-Mamoré, Jamary. Gy-Paraná, Aripuanã. Castanho, Porto Murtinho, cachoeiras do Xingú, e Tapajós.

Economic geology.—That the mineral resources of Matto Grosso are but little known is probably due, to some extent at least, to its difficult geographic position and to the fact that the geology of large areas in the state has never been studied. Hitherto it has produced gold and diamonds, and it is probable that gold can be dredged along some of the streams. Iron and manganese are said to exist in large quantities at Urucum (Evans), where they are near river transportation. A description of the geology of the iron and manganese ores shows a remarkable resemblance to that of Minas Geraes. The order of the rocks is as follows, from below upward: gneiss, mica schist, itacolumite, manganese and iron, mica schists, limestone. The beds are mostly horizontal. The hematite iron is said to be from 10 to 15 meters thick and the manganese is from 1 meter to 2.4.[71]

From an unpublished private report on the Urucum mines by Dr. Lisboa, and dated March, 1918, I am permitted to quote his description of the geology:

"In general the Urucum Mountains consist of a series of sedimentary rock to which I gave the name of Jacadigo series in 1907, and which consists of two characteristic formations. The lower one is of rough arkose becoming finer toward the top; the upper one, which is clearly separated from the lower one, consists of ferriferous sandstones. The iron and manganese occur in parallel beds in this upper division."

The Jacadigo series, regarded by Dr. Lisboa as pre-Devonian, is said to have a total thickness of from 250 to 500 meters; the rocks beneath them are granites and mica schists.

The manganese beds he reports as varying in thickness from less than one meter to five meters. His analyses show the manganese ores to run as high as 58.4 per cent of metallic manganese, or 60.8 per cent of manganese and iron together.

Geologic Maps of Matto Grosso

Evans, 1894.—Dr. J. W. Evans' paper on the geology of Matto Grosso, published in the Quarterly Journal of the Geological Society of London, volume L, pages 85-104, contains a small map showing the general geology of a large area along the Rio Paraguay between Coimbra and Diamantino. The map is on a scale of 1 to 2,500,000 (it is erroneously given on the map itself) and nine divisions of the geology are shown.

Lisboa, 1909.—Dr. Miguel A. Lisboa's report on the geology along the railway route between São Paulo and Matto Grosso, published at Rio

[71] Publio Ribeiro fé H. Kilburn Scott: O manganez no Brazil. p. 18. Rio de Janeiro, 1902.

in 1909 (Sul de Matto Grosso, etcetera), contains a geologic map of the southeastern portion of Matto Grosso. It is on a scale of 1 to 2,000,000 and shows ten geologic subdivisions. Most of the geology is the original work of Dr. Lisboa himself; it is a contribution of great value to the geology of Brazil.

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MINAS GERAES

Previous investigations.—The geographic details of the base map of Minas Geraes are taken chiefly from the Mappa do Estado de Minas by Benedicto José dos Santos, published in 1910.

It is somewhat remarkable that though Minas Geraes is the great mining state of Brazil, and though a vast amount has been written about it, its geology is probably less clearly understood than that of any state in that country. One reason for this is that the attention of the world has been directed to its mining rather than to its geology.

The establishment by the imperial government of the national "Escola de Minas" at Ouro Preto in 1875 and the opening of that school October 12, 1876, was a step of the greatest importance, not only for engineering education in Brazil, but also for the advancement of the science of geology in the state and throughout the whole country. Some of Brazil's ablest statesman and, with but few exceptions, all of her geologists and mining engineers have been educated at this school. It is maintained by the federal government and is now under the ministry of Agriculture, Indus-

try, and Commerce. The director from 1875 to 1891 was Dr. Henri Gorceix; the present director, who succeeded Dr. Gorceix in 1891, is Dr. J. C. Costa Sena, a native of Minas Geraes and a graduate of the school.

In this connection should be mentioned the establishment of the "Annaes da Escola de Minas," in which have appeared many valuable contributions to the geology and mineralogy of Brazil by the professors and students of the school. Fourteen numbers or volumes have been issued.

The state began a geological and topographical survey in 1892, under the title of Commissão Geographica e Geologica de Minas Geraes. Work was carried on until October, 1898, when it was suspended.[72] The following ten topographic sheets were published by this survey on a scale of 1 to 100,000, with 50-meter contours: Ayuruoca, Baependy, Barbacena, Carrancas, Ibertioga, Lavras, Lima Duarte, Luminarias, Rio Preto, and São João d'el Rei. Besides these topographic sheets the commissão published reports of progress which appeared in the form of five bulletins between 1892 and 1898. A geological sheet was prepared for publication in 1899, but before it could be issued the survey was suspended.

On the geology proper the following writers are noteworthy: Eschwege, Gorceix, Helmreichen, Pissis, Leith, Harder, and Chamberlin. In addition to the reports of progress of the Commissão Geographica e Geologica, valuable geologic notes made on trips through the state are those of M. A. R. Lisboa, Francisco de Paula Oliveira, J. C. da Costa Sena, Antonio Olyntho, and O. A. Derby.

Special mention should be made of the work done by Horace E. Williams, of the Serviço Geologico do Brazil, in northwestern Minas between south latitude 18° 30′ and 21°, and between west longitude 45° and 48°. The results of Mr. Williams' excellent work on this area have been sent me, but unfortunately they reached me too late to be incorporated in the map.

General geology.—Archean rocks cover a larger area in the state of Minas than any other one division of the geologic column. They are exposed over nearly all of the southern and eastern parts of the state, occupying an area of 266,600 square kilometers out of a total state area of about 580,000 square kilometers. Included in this Archean area, however, is the old Paleozoic series mentioned in the following paragraph.

Thrust-faulted into the Archean are certain old metamorphosed Paleozoic rocks that now appear as quartzites, schists, itacolumites, marbles, and as iron and manganese ores. These infaulted areas are often small

[72] The following were directors at different periods:
Augusto de Abreu Lacerda, 1892 to 1895.
Alvaro da Silveira, 1895 to 1898.

and unimportant isolated masses, but again they are hundreds of kilometers in length, while in area they cover thousands of square kilometers. On account of lack of knowledge of the details of their distribution, many of the smaller areas are included in the area of the Archean rocks given in the preceding paragraph. As a rule, they form belts or zones and they frequently appear as parallel ridges or mountain ranges. The rocks thus infaulted are generally metamorphosed, and, as they are more resistant than the surrounding granites and gneisses, they usually form the prominent features in the topography of the region.

The age of these old sediments is not known, and they are therefore represented on the map simply as early Paleozoic. They are probably older than the Carboniferous. Their structural relations to the Archean rocks are well shown in the accompanying section from the paper by Harder and Chamberlin, page 368.

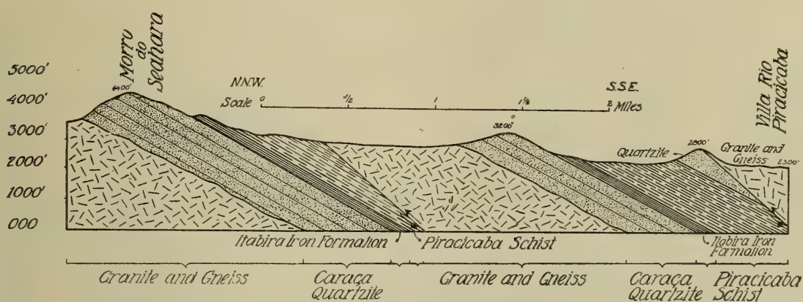

FIGURE 13.—*Slice-faulted Section*

This section is between Villa Rio Piracicaba and Morro do Seahara.—Harder and Chamberlin.

The next newer rocks are probably a series of sandstones or quartzites corresponding to and continuous with the diamond-bearing quartzites of the State of Bahia. These rocks are exposed at Grão Mogol, in the north of Minas, where they are diamond-bearing just as they are in Bahia, and like those in Bahia they are referred provisionally to the Carboniferous.

The structural relations of these quartzites are fairly well shown in the section published by Helmreichen in 1846, and by Gorceix in 1884.

Rocks of this series are probably exposed at many places about the edges of the Permian and even inside of it. They can not be clearly discriminated with our present knowledge, for much confusion has been caused by the use of the word "itacolumite" for sandstones and quartzites of many kinds and of several different geologic horizons.

In view of all the data available, it seems probable that the diamonds of Minas Geraes have come directly from these Carboniferous quartzites,

just as they do in Bahia, and that they occur in the Permian where they have been redeposited, and that outside of existing Carboniferous and Permian areas they occur where the older beds have been removed during long periods of denudation.

The next higher beds are the Lower Permian sediments, whose contact with the Archean enters the southern end of the State from São Paulo just north of the city of Jacuhý, and runs northward and eastward past Formiga, Pitanguy, Santa Luzia, west of Diamantina, east of Montes Claros, Monte Alto, in Bahia, and seems to end east of the Rio São Francisco at a point about thirty kilometers south of Bom Jesus da Lapa. The Lower Permian has not hitherto been recognized as such in the State of Minas Geraes, and the reference of certain beds to that horizon is based partly on the character of the rocks and partly on their tying up with the known Lower Permian of the State of São Paulo. The position of the base of the series as shown on the map has been gathered from miscellaneous notes on the geology of the region, and can not therefore be accepted as anything more than an attempt to locate the margin of the series believed to be Lower Permian. The question of the Permian as a whole and the evidence bearing on it is discussed under the head of "Permian," at page 38.

The rocks of the series are shales, sandstones, limestones, and conglomerates that have been but little affected by folding or faulting. In Minas these beds form extensive tablelands and are deeply trenched by the streams. There seems to be strong presumptive evidence of glacial deposits at the base of the series at several places, but it requires confirmation, so far as Minas is concerned.

The large area of limestone in the valley of the Rio São Francisco in the north end of the state and north of the confluence of the São Francisco and the Rio das Velhas has not been studied. It is assumed that these limestones are of the same age as those east of the river, namely, Permian. See discussion under Permian.

There are a few small lake deposits in the state of Tertiary age. The best known are those at Gandarella and at Fonseca, which have been described by Gorceix.[73]

The Gandarella basin is northwest of Ouro Preto, about half way between Conceição and Santo Antonio. The rocks are clays, gravels, sands, and lignites. One bed of lignite is a meter in thickness.

The Fonseca basin is northeast of Ouro Preto, near the village of that name and close to Rio Piracicaba, east of the town of Agua Quente. The

[73] H. Gorceix: Bacias terciarias d'agua doce. Annaes da Escola de Minas no. 3, pp. 95-114. Rio, 1884.

deposits are horizontal beds laid down in a basin of Archean rocks. They consist of beds in the following order from the top:

	Meters
1. Canga, or iron conglomerate	..
2. Fossiliferous clay shales	5
3. Sands and clays	22
4. Bituminous shales	±5

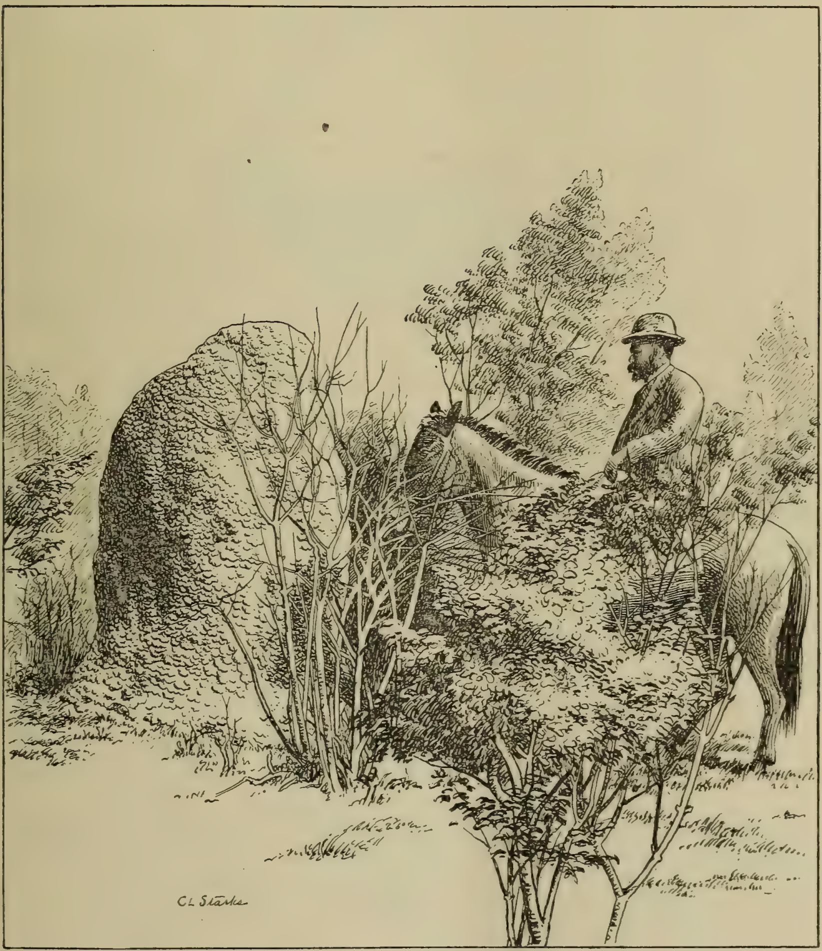

FIGURE 14.—*Above-ground Structure of White Ants*
View taken seven kilometers west of Queluz, State of Minas Geraes.

The remarkable cave deposits of Minas Geraes and their Pleistocene fossils have been collected and studied by Peter Lund, a Danish natural-

ist, who spent forty-seven years (1833-1880) in his Brazilian explorations. His materials were described by various specialists, notably by Hansen, Lütken, Quatrefages, Reinhardt, Warming, and Winge.

The hard cones of earth built over the surface of the ground by termites ("white ants") in many parts of the interior are impressive and are probably of some geologic importance. The true ants also make extensive underground galleries.

Economic geology.—Minas Geraes is the chief mining State of Brazil.[74] It has an unusually large number of minerals of economic importance, though only gold, manganese, iron, and diamonds have ever been extensively worked. It was in Minas that gold was first discovered in Brazil, about 1693, and the earliest mining done in that country was for gold in what is now that state. For some years Brazil was the leading gold-producing country of the world. Though there have been and still are a few notable rock mines in the old Paleozoic series where the gold originated, most of the gold of Brazil has come from placer deposits. Among the many writers on the gold deposits of Minas whose papers are worthy of especial attention are Claussen, Eschwege, Ferrand, and Ferraz.

The discovery of diamonds in Minas became known about 1724,* and from a few years after that until the discovery of the diamond mines of South Africa, Minas was the leading diamond-producing region of the world. The diamonds have come chiefly from the placer deposits, though many stones have been found *in situ,* especially about Grão Mogol. The diamonds are not so widely distributed as gold. Something about the theories of the origin and distribution of diamonds will be found under the head of "diamonds," at page 234. The following authors have written on the diamond deposits of Minas: Galogeras, Campos, Claussen, Derby, Eschwege, Gorceix, Mawe, Hussak, Heusser and Claraz, and Oliveira.

The manganese deposits of Minas first attracted attention in 1893, and in 1894, 1,430 tons of the ore were exported,[75] and since 1896 that state has been one of the great manganese-producing regions of the world.

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[74] For references to the mining laws of Brazil and of Minas Geraes, see "Mining laws," at page 16 et seq.

* The discovery of diamonds was claimed to have been made in 1723 or 1724 by Bernardo da Fonseca Lobo, and his claim was recognized by the crown of Portugal February 26, 1734 (Revista do Archivo Publico Mineiro, Anno II, fasc. 2, pp. 271-273. Ouro Preto, 1897). As a reward "The King, our Lord . . . sees fit to bestow upon him the post of chief captain of the Villa do Principe [now called Serro] during his lifetime, residence of the same every triennium, the office of notary of the Villa do Principe, and one hundred milreis pension money for his two sisters, Maria Nunes Machado and Margarida Nunes Machado, . . . from which each of them shall cede twelve milreis to the persons they are to marry that they may receive the habits of the Order of Christ which he will have bestowed upon them at Occidental Lisbon April 12, 1734."

[75] Herbert K. Scott: The manganese ores of Brazil. Journal of the Iron and Steel Institute, vol. lvii, p. 189. London, 1900.

The ores occur at two horizons, namely, in the Archean complex and in the early Paleozoic series of rocks. The mines worked are in the vicinity of Lafayette, in the Archean, and at Miguel Burnier, on the Central Railway, in the Paleozoic. Later discoveries have been made on the properties of the Saint John del Rey Mining Company at Capitão do

FIGURE 15.—*Brazilian method of Diamond washing with the wooden Batea*

Matto and Cachoeirinha near Morro Velho. Valuable papers on the manganese deposits of Minas are by Derby, Greven, Lisboa, Lustosa, Michaeli, Scott, Singewald, and Thomas.

The iron deposits of Minas have long been known, but only within a few years have they attracted the attention to which they are justly entitled. They are probably the most important iron ores known, though they are as yet but little used. A paper by Dr. Francisco de Paula Oli-

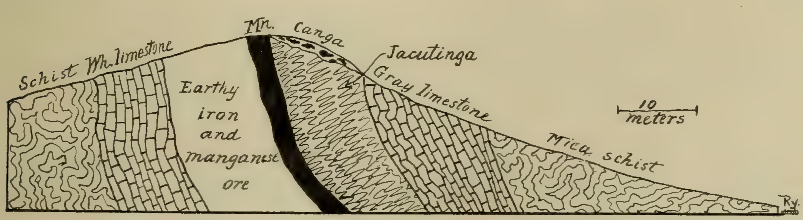

FIGURE 16.—*Section at the Miguel Burnier Manganese Mines*
This section is at kilometer 501 of the Central Railway. After Scott.

veira, published in the Annaes da Escola de Minas, number 3, pages 135-194, tells of the efforts to make iron in the state. The iron ores are in sedimentary rocks, either in and forming parts of the early Paleozoic rocks or they are later deposits derived therefrom. The most important papers on the geology of the ores are those of Chamberlin, Berby, Dupré,

Eschwege, Ferrand, Graça, Gorceix, Harder, Leith, Lisboa, and Scott. Derby points out, however, in his paper on "The iron ores of Brazil," published in "The iron-ore resources of the world" (Stockholm, 1910, page 817), that the work on the Minas iron ores reported in his paper was done almost exclusively by Dr. Gonzaga de Campos.

Many other minerals are known, but as yet they are not developed. Among these the following appear to be the more important:

Nickel has been found in the Archean area of southern Minas. The deposits are described by H. E. Williams, of the Serviço Geologico do Brasil, the title of whose paper is given below.

Platinum has long been known to occur in connection with the auriferous iron sands of the old Gongo Soco mines and in the alluvial diamond deposits. No effort has been made to recover it.

Marbles and limestones are found in great abundance, but, aside from their local use for the manufacture of lime, they are undeveloped. The marbles are mostly from the Archean regions. Especially attractive varieties of marble are reported from Gandarella.[76] Amorphous limestones are abundant in the Permian regions, in the upper part of the Valley of Rio das Velhas, and in the northern part of the state, near the Rio São Francisco. At Paineiras, near Uberaba, limestone is quarried in what are supposed to be Cretaceous rocks.

Asbestos is reported from the vicinity of Santa Luzia.

Talc is abundant in the Brazilian complex associated with metamorphic rocks.

Mica is known at Bicas, Fonseca, Manhuassú, Santa Luzia, and it is to be looked for in pegmatite dikes anywhere within the Archean area of the state.

Niter deposits are found in the limestone caves of the state.

Graphite is found in veins in the Archean rocks in the vicinity of Minas Novas and at São Miguel. The deposits are described by Dr. J. C. da Costa Sena.[77]

Extensive deposits of bauxite have been found by Dr. George Chalmers at Motúca on the property of the Saint John del Rey Mining Company near Villa Nova de Lima.*

Phenacites are found at Piracicaba.

The mineral waters of Minas are among the important economic geologic products of the state. The thermal waters of Poço de Caldas are

[76] F. de Paula Oliveira: Revista Industrial de Minas, vol. iv, p. 275, 30 de Março de 1897.

[77] Annaes da Escola de Minas, vol. ii, pp. 125-129. Rio de Janeiro, 1886.

* Eighty-eighth Ann. Rept. of the directors of the Saint John del Rey Mining Company, London, June, 1919, pp. 59-60.

worthy of special attention. The waters of Caxambú and Limbarý are well and favorably known in the Brazilian market.

Besides those noted by Gorceix in the Tertiary basins, bituminous shales are said to occur in the Serra de Sete Lagoas.*

A valuable book in connection with the history of mining in the State of Minas is the Historia do Districto Diamantino, by Dr. Joaquim Felicio dos Santos, published at Rio de Janeiro in 1868. Those who visit the region will be interested to read Mawe's Travels, first published at London in 1812, and at Philadelphia and Boston in 1816. Mawe was an English mineralogist and was the first foreigner permitted to visit the diamond regions of Brazil.

The climate of Minas Geraes is remarkably fine and healthful; the region is high and well watered and in many places well timbered.

Geologic Maps of Minas Geraes

Pissis, 1842.—In 1842 the French Academy of Science published A. Pissis' "Mémoire sur la position géologique des terraines de la partie australe du Brésil," etcetera, and that paper was accompanied by what is called a geologic sketch-map (Esquisse géognostique) of the gold region of Minas Geraes. It embraces an area of something more than 9,400 square kilometers, from 10 kilometers south of Ouro Branco to Cocaes on the north. The map is on a scale of 1 to 250,000 and four geologic divisions are shown, namely: gneiss, talc, quartzite, itabirite, and limestone.

That same paper contains another geological map that embraces the region from Bahia on the north to Piracicaba, São Paulo, on the south, and all of the province of Minas Geraes east of Rio São Francisco. The scale of this map is 1 to 2,500,000 and the following geologic divisions are shown: four for the "terrain primitif"; two for the "periode phylladienne"; one for diorite; two for the Tertiary.

Harder and Chamberlin, 1915.—The small map published by Harder and Chamberlin in connection with their article on the geology of central Minas Geraes, in the Journal of Geology, May-June, July-August, volume XXIII, page 341, etcetera, shows the general geology of the region extending from Queluz to Diamantina and about one degree wide. The scale is about 1 to 22,000,000 and seven geologic divisions are shown.

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* E. Liais: Climats, Géologie, etc., du Brésil, Paris, 1872, p. 130.

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PARÁ

Previous investigations.—A good résumé of the geology of Pará is given by Katzer in his Grundzüge der Geologie des unteren Amazonasgebietes, Leipzig, 1903. I have followed his map in the main, but with modifications on certain points. The distribution of the various formations on the southern side of the Amazon, as shown on Katzer's map, is especially uncertain. The Carboniferous has been certainly recognized south of the Amazon in the State of Pará only on the Tapajos; the Silurian, Devonian, and Cretaceous have not been certainly recognized in Pará on the south side of the Amazon at all. The ages of the rocks of areas so represented must therefore be considered as yet in doubt. The area shown as Carboniferous or Permian about the confluence of Rios Araguaya and Tocantins I have shown as Permian, because it thus fits on to the known Permian of Maranhão without doing violence to Katzer's views. The occurrence of Devonian beds on the Araguaya is very doubt-

ful, and the Cretaceous probably does not reach that river on the west. I have purposely omitted Katzer's distribution of eruptive rocks in the State of Pará. Data for such a map are not available in any part of Brazil. Katzer's geologic map of Pará should only be used in connection with the text which it accompanies.[78] The best original papers on the geology of Pará are those of Derby, Hartt, Smith, and Katzer. The fossils are described by Clarke, Derby, and Rathbun. The geology along the Oyapok and on the boundary with French Guiana is outlined in Velain's description of the rocks collected there by Crevaux. The outlines of the floodplain of the Amazon between 54 degrees and 56 degrees are taken from Herbert H. Smith's map in his "Brazil, the Amazon and the Coast."

General geology.—The Amazon River follows a synclinal trough across the State of Pará. The northern and southern parts of the State are Archean, against which are deposited Silurian rocks on the north and Devonian and Carboniferous on both the north and south sides. From western Pará the Paleozoic sedimentary beds extend into the State of Amazonas, but they are not certainly known east of the Tapajos, on the south side of the Amazon, or east of Rio Maecurú, on the north side, though it seems reasonable to suppose that they do extend farther east on both sides. Rocks of later, but of uncertain, age are found at many places through the middle of the valley. Following the coast north and south of the mouth of the Amazon are horizontal sedimentary beds probably of Tertiary age. Fossils found at Pirábas and at other points on the coast east of Salinas show that some of these beds are certainly Eocene, as Miss Maury has pointed out. (See bibliography.)

Economic geology.—Gold is found in the Archean area along the streams that flow directly into the ocean from the Guiana highlands. Limestones occur in the Carboniferous beds at Itaituba, and are reported in the mountains of the southeastern part of the state. Very little is known as yet, however, of the geology of the southern part of the State of Pará, and the economic geology is therefore necessarily unknown and undeveloped.

Geologic Maps of Pará

Ch. Velain, 1885.—In 1885 M. Ch. Velain published in the Bulletin de la Société Géographique de France a paper on the geology of French Guiana, "Esquisse géologique de la Guyane française," using the data collected by Dr. J. Crevaux in his explorations. The article is accompa-

[78] F. Katzer: Grundzüge der Geologie des unteren Amazonas-gebietes. Leipzig, 1903.

nied by a geologic map that embraces nearly all of northeastern Pará from Obidos to the mouth of the Amazon. It is on a scale of 1 to 6,000,000 and shows ten lithologic subdivisions.

Katzer, 1903.—In his Grundzüge der Geologie des unteren Amazonasgebietes, Dr. F. Katzer gives a geologic map of the State of Pará on a scale of 1 to 4,400,000. Many subdivisions of the eruptive rocks are given; of the sedimentary beds he makes eight divisions, including the alluvial deposits.

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PARAHYBA

Previous investigations.—The geography of the State of Parahyba is taken from the maps of the Inspectoria de Obras Contra as Seccas, made under the direction of Dr. M. Arrojado R. Lisboa.

The papers of Branner, Crandall, Soper, and Williamson contain nearly all that is known of the geology of the State of Parahyba. There are a few valuable notes made by Agassiz at Parahyba and by Burlamaqui in the interior. The geologic map of this state is chiefly from the personal observations of the author.

General geology.—The Brazilian complex covers all of the State of Parahyba except a belt, about forty kilometers wide, along the seacoast, and an infolded area, probably Cretaceous, of about twelve hundred square kilometers at and west of Souza, on its western frontier. The Archean rocks are cut by basic intrusives. There are some isolated patches of Mesozoic or Cenozoic deposits in the mountain tops near and west of Teixeira—remnants of beds that have been removed by denudation. The rocks of the Brazilian complex in Parahyba are mostly highly inclined (50 to 75 degrees) crystalline schists, gneisses, and granites cut by quartz veins in which gold has been mined. Williamson, cited in the bibliography, gives a section, opposite page 116, six miles long, in the Valley of Rio Bruscus.

Along the coast is a belt of Cretaceous and Tertiary sediments that nowhere exceed a width of 50 kilometers. The Cretaceous rocks are mostly impure marly limestones that are exposed in the quarry at the city of Parahyba and along the railway between Parahyba and Cabedello. These limestones contain fossils, cephalopods, fish remains, and crustacea that indicate their Cretaceous age. Careful search has not been made at other places, but it is quite probable that these Cretaceous beds extend both north and south of Parahyba, though they do not appear on the open coast. Owing to poor exposures, it is not possible to give the thickness of the Cretaceous in Parahyba; the total thickness visible is only about twenty meters, but neither the top nor the bottom of the series was seen.

Overlying the Cretaceous are the horizontal particolored Tertiary beds that form the vertical bluffs of Cabo Branco and elsewhere along this part of the coast.

Economic geology.—Gold was formerly mined from the quartz veins in the Archean area near Piancó, but the mines have long been abandoned and no mines are now operated in the state.

It is claimed that there is much iron in Parahyba, but there is no

trustworthy information available in regard to its location, quality, or quantity.

Limestone is quarried from the Cretaceous beds at the city of Parahyba, and there has been talk of the utilization of that rock for the manufacture of Portland cement, but no serious attempts have been made at such manufacture.

Marble is found at various places within the Archean area, and it is said that it has been used locally for the manufacture of lime, but otherwise it is undeveloped.

Geologic Maps of Parahyba

Branner, 1902.—A geologic map of the eastern end of the state is given in Branner's paper on the "Geology of the Northeast Coast of Brazil," as plate 4 of volume 13 of the Bulletin of the Geological Society of America, 1902. It shows the approximate extent of the Cretaceous and Tertiary sediments in that State.

R. H. Soper, 1913.—Publication number 26 of the Inspectoria de Obras Contra as Seccas, entitled "Geologia, etc., do Rio Grande de Norte e Parahyba," by Ralph H. Soper, contains a sketch-map of the geology of Parahyba on a scale of 1 to 1,000,000 and with four subdivisions of the geology, namely: (1) gneisses, schists, and granites, (2) sandstones, (3) limestones, (4) sands and clays.

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PARANÁ

Previous investigations.—The most important papers on the geology of Paraná are those of Derby, Oliveira, Siemiradzki, White, and Woodworth, while the report of Clarke on the Devonian fossils is the most important on the paleontology. Of these the late report of Dr. Euzebio Paulo de Oliveira is the most comprehensive, and brings our knowledge of the geology of that state up to date. By an unfortunate oversight his paper was published without the author's name. It is entitled "Geologia do Estado do Parana" and appears at pages 67 to 143 of the Boletim do Ministerio da Agricultura, Industria e Commercio, anno V, Rio de Janeiro, 1916. Unfortunately the base map of Paraná mentioned by that writer does not accompany the report and has not been available.

Some good general descriptions of Paraná are given by Henry Lange in his Südbrasilien. Bigg-Wither's book is a valuable work on the State of Paraná, but it has very little on the geology.

General geology.—The geology of the State of Paraná is simple, but it includes an unusually wide geologic time range. On the coast and forming the high escarpment that faces the ocean are the Archean granites, gneisses, schists, and intrusives. Resting directly on the Archean are certain metamorphosed rocks—schists, limestones, and quartzites—that Euzebio de Oliveira calls the Devonian complex. Their precise age is not known, but it seems probable that they, or some of them, represent the older Paleozoic of other parts of Brazil. On these and on the westward slope of the Archean rests the Devonian rocks, which are here represented by a basal conglomerate, the Furnas sandstones, and the Ponta Grossa

shales, with a total thickness of 250 meters, all of them dipping gently westward. The Ponta Grossa shales have furnished abundant fossils that have been described by John M. Clarke, and there is no uncertainty about the age of the rocks from which they come. Overlying the Devonian beds are the Lower Permian sandstones and shales, with evidences of glaciation, followed by the Upper Permian shales, sandstones, flints, coal, and fossil plants. Both divisions of the Permian cross the entire width of the state from Rio Itararé, São Paulo, to Santa Catharina, on the Iguassú.

West of the Permian are the Triassic sandstones (Botucatú), with their accompanying sheets and dikes of eruptive rocks. In Paraná the Triassic beds have thus far furnished no fossils.

Siemiradski thinks the region of the Paraná highlands is profoundly faulted. There is no doubt about the existence of faults all through the

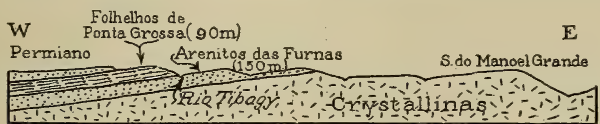

FIGURE 17.—*General east-west Section south of Tibagy, Paraná*
According to Eusebio de Oliveira.

region, but thus far the great dislocations suggested by that geologist have not been verified.*

Economic geology.—Molybdenum is said to occur in the Archean rocks on Rio Capivary, 30 kilometers from Curytiba. Coal of Permian age is found on the Rio das Cinzas, in the northern part of the state, and diamonds have been mined along some of the streams that flow from and across the Devonian area. The Iraty shales at the base of the Upper Permian are bituminous, and asphalt is said to occur in veins in the Upper Permian in the southern part of the state.

Limestones in the form of lenses in the Archean occur on the Curityba plateau, especially at Pangaré. In the older Paleozoic series are also limestones north of Curityba and between Cachoeira and Rocinha and at Itaiacoca. Limestones are also common in the Permian at many places.

Geologic Maps of Paraná

I. C. White, 1908.—Accompanying Dr. I. C. White's "Final Report on the Coal Measures . . . of South Brazil" is a map of the States of

* J. von Siemiradski: Geologische Reisebeobachtungen in Sudbrasilien. Sitz. der K. Akad. Wiss. Wien., 1898, 25.

Rio Grande do Sul, Santa Catharina, Paraná, and part of São Paulo, showing the general distribution of the Permian coal-bearing horizon and of the overlying rocks. Only two geologic divisions are shown, the Tubarão (coal-bearing) series and the overlying beds, and these are not given in detail. The scale of the map is 1 to 2,010,365. The date on the map is 1907, but the report itself was printed in 1908.

Euzebio Paulo de Oliveira, 1913.—A small geologic map of a part of the state is given at page 63 of Dr. John M. Clarke's Devonian Fossils of Paraná. It is on a scale of 1 to 1,000,000 and shows three geologic divisions, namely: Furnas sandstones, the Ponta Grossa shales, and the overlying beds—called Carboniferous in the legend. Though the area represented is but small, the map affords a good key to the geology of the state within the area of the Devonian rocks. The report in which the map appears was published at Rio de Janeiro in 1913.

Euzebio Paulo de Oliveira, 1918.—The Serviço Geologico e Mineralogico do Brasil published at Rio in 1918 a report by Euzebio Paulo de Oliveira entitled "Regiões carboniferas dos Estados do Sul," which contains an "esboço geologico da ragião—typo do Sul do Brazil," which is really a geologic map of the State of Paraná. It is on a scale of one to two million and eight geologic divisions are shown. This is the best, and indeed the only, geologic map of the State of Paraná.

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PERNAMBUCO

Previous investigations.—The geography of the state is taken from the maps of the Inspectoria de Obras Contra as Seccas.

The general geology of the State of Pernambuco is fairly well shown in Branner's geology of the northeast coast of Brazil, which was made from personal observations. Notes on the geology of the interior of that State are given by Halfeld along the São Francisco, by Coutinho on the line explored for a railway from Recife to the São Francisco, by Lom-

bard in his "Exploração da parte sul do estado de Pernambuco," and by Dombré in his "Viagens." A strip in the west end of the state is shown on Small's map of the geology of Piauhy. The fossils from Farinha are dsecribed by Cope, Dall, C. A. White, and Rathbun, and Miss Maury contributes a valuable note on the correlations of the Maria Farinha beds.

The island of Fernando de Noronha belongs to the State of Pernambuco; the geology of that island is described by Branner, Darwin, Davis, Lea, Renaud, Ridley, Geo. H. Williams and Gill, and Costa.

The stone reefs of the State of Pernambuco and the east coast are described by Branner.

General geology.—Rocks of Archean age cover most of the State of Pernambuco. Along the coast is a belt of Tertiary sediments; north of Olinda this belt is about forty kilometers wide, and in some places is underlain with Cretaceous rocks; south of Olinda this belt is only ten or twelve kilometers wide and the rocks are probably all Tertiary. In the extreme western end of the state the mountains along the Piauhy and Ceará frontiers are capped by Cretaceous rocks containing fossil fishes. At several places through the interior old Paleozoic remnants are faulted or folded into the Archean. For lack of data these infaulted areas have not been outlined; one of them is in the Serra Russa between Victoria and Gravatá. A similar area is west of Canhotinho. The outliers of sedimentary rocks between Jatobá and Buique and near Aguas Bellas have thus far yielded no fossils, and the age or ages of those beds is not definitely known. They are referred provisionally to the Upper Permian because they are stratigraphically in the place occupied by the Permian beds at Aracý, Bahia. Lombard supposed the beds at Buique were pre-Cambrian, but there is no evidence in support of such a theory (Lombard, "Relatorio apresentado," page 131. Recife, 1895). Trachytes are exposed on the coast just north of Cape Santo Agostinho, and the island of Santo Aleixo is of rhyolite. The island of Fernando de Noronha is mostly phonolite, but there are some small areas covered by sandstones formed by the hardening of sand-dunes.

The stone reefs characteristic of the Brazilian coast from Ceará to Bahia, inclusive, are well developed at several places on the coast of Pernambuco, notably at Rio Formoso, Recife, and just south of Cape Santo Agostinho. Several Brazilian seaports are formed by stone reefs, namely, those of Pernambuco, Natal, Porto Seguro, and many of minor importance. These reefs are old sand beaches through which water from the land has filtered, consolidating the sand by the precipitation of lime between the sand grains. They vary greatly in length and breadth; the one at Pernambuco is from 20 to 60 meters wide. Their surfaces never rise above high-tide level.

These sandstone reefs have been in process of formation since Pliocene times and are still being formed. The accompanying cross-sections of the reef at Rio Formoso show their general structure along the entire coast.

Economic geology.—Beautiful crystalline marbles are found at many places in the Archean areas of the state, notably at São Caetano, Floresta, Pajeu de Flores, and Aguas Bellas. Some of these marbles are pure limestones, and are much used in the manufacture of lime for local consumption, while others are dolomites. The rhyolites of the island of Santo Aleixo and the phonolites of Fernando de Noronha have been extensively quarried for street paving blocks. The sandstones of the reefs were formerly much used for building stones and for paving sidewalks in the city of Recife. The use of these sandstones, however, has been wisely

FIGURE 18.—*Sections across a typical Sandstone Reef at Rio Formoso, State of Pernambuco*

The ocean is on the right. The horizontal lines represent high and low tide.

prohibited on account of the protection afforded the ports and the coast by the stone reefs.

Limestones of Cretaceous age are abundant in the Serra do Araripe, in the northwestern corner of the state. At Maria Farinha on the coast north of Olinda, limestones are found at the base of the Mesozoic sediments.

One may often hear of the existence of rock-salt in the mountains about Buique. The salt that has been made at Buique, however, is obtained by leaching the dry earth or efflorescence gathered from certain sandstones and evaporating the waters.

Saltpeter is also found in the Buique region, but the deposits are formed only on certain porous sandstones where the efflorescence is scraped from rock surfaces on which it is formed by evaporation.[79]

[79] L. Lombard: Revista Industrial de Minas Geraes, vol. v, pp. 6-7. Ouro Preto, 20 de Junho de 1897.

On Ilha Rapta, one of the islands forming the Fernando de Noronha group, are limited phosphate deposits that attracted considerable attention at one time. Analyses of the materials are given by Lima José Ig. d'Abreu and by Lasne. Attempts were made to export these phosphates, but, owing to the difficulty of loading them, the enterprise was soon abandoned.

Geologic Map of Pernambuco

Branner, 1902.—A geologic sketch-map of "the region about Pernambuco" forms plate 11 of Branner's paper on the geology of the northeast coast of Brazil (opposite page 62 of volume 13, Bulletin of the Geological Society of America, 1902). It is on a scale of 1 to 1,000,000 and shows only two divisions—the Archean and the Tertiary.

The geology of the extreme western end of the state is shown on the map accompanying Small's Geologia e supprimento d'agua . . . no Piauhy, publicacão 32, da Inspectoria de Obras Contra as Seccas, Rio de Janeiro, 1914.

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PIAUHY

Previous investigations.—The map of Piauhy east of Floriano is taken from Small's Mappa geologico do Piauhy, published in 1914 by the Inspectoria de Obras contra as Seccas under Dr. M. A. R. Lisboa, while the part west of Floriano is from the map published by Dr. José Estacio de Lima Brandão under the Inspectoria Federal das Estradas in 1913.

There are two important papers on the geology of Piauhy, that of Dr. Lisboa on the Permian geology of northern Brazil, and that of H. L. Small on the "Geologia e agua subterranea de Piauhy e Ceará." Since these papers came out I have received specimens of *Psaronius* from Rio Parnahyba below Philomena which show the further extension of the Permian in the southern part of the state. The notes of George Gardner, of Spix and Martius, and of J. W. Wells are fragmentary, but useful.

General geology.—The Archean rocks are exposed in Piauhy only in the southeastern part of the state, where it joins Ceará, Pernambuco, and Bahia, and in a small area near the north end of Serra Grande.

The oldest sedimentary beds known in the state are those of the Serra Grande, supposed to be of lower Permian age. These rocks are conglomerates, sandstones, limestones, and calcareous shales. The strata are often false-bedded, and the series has a maximum thickness of 700 meters. The beds dip toward the west or northwest, at an angle of from four to seven degrees. No fossils have been found in the rocks of this group in Piauhy and their age is not certainly known.

Overlying the Serra Grande series are the Upper Permian sediments, which consist of a series of horizontal, reddish calcareous sandstones and

shales having a thickness varying from 100 meters or less in the valleys to more than 500 meters in the high mountains. Mr. Small gives the following order and thickness of the Permian rocks of Piauhy:[80]

	Thickness in meters
1. Upper yellow sandstone, sometimes false-bedded	250
2. Middle sandstones and sandy shales	200
3. Sandstones and lower shales	70

The determination of the Permian age of this series rests on the presence of *Psaronius,* which has been found by Dr. Lisboa at many places in this state and in Maranhão, and on a *Sigillaria* found by Mr. Small 30 kilometers east of Valença, near the east base of the Serra Baptista.

In the southeast corner of the state Cretaceous beds overlie the Upper Permian beds at a few places. The western end of the Serra do Araripe, where it projects into Piauhy, is known as the Serra Vermelha. The upper portion of that mountain is made of the same kinds of horizontal Cretaceous sedimentary beds as those of the Serra do Araripe. A little farther south, on the divide between the States of Piauhy and Pernambuco, is the Serra de Dois Irmãos, which, together with a small outlier to the west of it, is likewise Cretaceous. All of these Cretaceous areas of Ceará, Piauhy, and Pernambuco are merely the remnants of the original wide-spread beds of Cretaceous age. A fuller description of the Cretaceous geology of this region is given under the notes on the geology of Ceará. At several places eruptive rocks appear at the surface, notably at Valença, on the headwaters of Rio Berlenga, and at fazenda Grauta northwest of Picos.

Economic geology.—Piauhy is an agricultural and pastoral rather than a mineral-producing state. The geology in its relations to underground water is of special interest and has been reported on by H. L. Small. (See bibliography.) Iron of excellent quality has been reported, but nothing is now known of the quality or of the quantity available.

Geologic Maps of Piauhy

Lisboa, May, 1914.—Dr. M. A. R. Lisboa's paper on the Permian geology of northern Brazil, published in the American Journal of Science for May, 1914, pages 425-443, is accompanied by a small-scale sketch-map showing the geology of a large part of the State of Piauhy. The scale is 1 to 11,428,570 and four geologic subdivisions are shown, namely: crystalline rocks, Permian, Triassic, and Cretaceous.

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[80] Relatorio, pp. 64-65.

Small, June, 1914.—In his report to the Inspectoria de Obras Contra as Seccas, publicação number 32, on the geology and underground waters of Piauhy, etcetera, Mr. H. L. Small gives a geologic map of the eastern and northern parts of the State of Piauhy. It is on a scale of 1 to 1,000,000 and shows seven geologic subdivisions. The map does not include the southwestern part of the state west of latitude 43 degrees, but it does include the western portion of the States of Ceará and Pernambuco. The map is accompanied by sections showing the geologic structure.

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RIO DE JANEIRO, THE FEDERAL DISTRICT, AND TRINIDADE

Previous investigations.—This territory includes the Federal District and the island of Trindade.

Almost every geological visitor to Brazil has stopped at Rio de Janeiro and has had something to say about the geology in and about that city. The geology, however, is rather monotonous and the notes usually begin

and end with the remark that the rocks are granites and gneisses. The most comprehensive papers are those of Pissis, Eschwege, Caldcleugh, Derby on the eruptives in Rio de Janeiro, and of Alberto Paes Leme on "os gneiss do Rio de Janeiro." Others are mostly field-notes; such are those of Burmeister, Hartt, Burton, Collie, Eschwege, and D'Orbigny.

The island of Trindade, in south latitude 20° 30′, west longitude 29° 25′, belongs to the Federal Union and, together with the Federal District, is here included with the State of Rio de Janeiro. The island is shown as an inset on the map of Brazil.

General geology.—Archean rocks cover all of the state except a narrow belt of Tertiary and Quaternary sediments on the coast and some isolated patches of Tertiary lake deposits in the valley of the Parahyba.

Of the geologic structure of the State of Rio de Janeiro but little is known, for the character of the rocks, the depth of decomposition, and the presence of dense forests render field-work difficult and unsatisfactory. The only attempt to work out the structure of any considerable part of the geology about the city of Rio de Janeiro is reported in the paper of Alberto Paes Leme, entitled "Estudo geologico de uma parte do districto federal," cited in the bibliography that follows. It seems evident at a glance that the granites, gneisses, schists, and eruptives of the region have been much faulted, profoundly decomposed, and extensively denuded. The Tertiary lake beds referred to have been reported only from two places in the State of Rio de Janeiro, namely, Barra Mansa and Rezende. They are evidently the eastward prolongations of the Tertiary beds found at Taubaté, but separated by denudation from the larger original areas.

At many places near the coast lakes have been shut in by Quaternary and late sediments that have been thrown into the embayments by the ocean. The geography of the coastal region is especially interesting, and a careful study of it would throw much light on the geological history of the region and of the country. But little attention has been given to this subject, however. It is spoken of briefly in Branner's "Stone reefs of Brazil," at pages 124, 128, and 132.

The uninhabited island of Trindade is entirely of eruptive rocks—phonolites.

Economic geology.—The economic geologic products of the State of Rio de Janeiro, including the Federal District, are limited chiefly to building stones, marbles, and ceramic clays.

The quarrying industries of the state, and especially those in and near the city of Rio de Janeiro, are of great importance and have had a striking influence on the character, dignity, and stability of the architecture

and port works, not only of Rio de Janeiro itself, but on the architecture of all of the coast cities of Brazil as well.

In the Archean area there are crystalline marbles which, though as yet but little used, must in time come into the market, both for building and ornamental purposes, and also for the production of lime and possibly of Portland cement. Such limestones are known at Macuco and Santa Rita near Catagallo, on Rio Muriahé above Caxoeira, at Sant' Anna north of Rezende, near Barra Mansa, and near Barra do Pirahy, and in the mountains east of Belem.

It is possible that in the areas of Tertiary lake deposits near Barra Mansa and Rezende there may be found bituminous shales similar to those at Taubaté.

Geologic Maps of Rio de Janeiro

Pissis, 1842.—In 1842 A. Pissis presented to the Academy of Sciences of Paris a "Mémoire sur la position géologique des terrains de la partie australe du Brésil," etcetera, and that paper was accompanied by a geologic map that embraced the region between the city of Bahia on the north and east and Piracicaba, in the province of São Paulo. It therefore included the entire provinces of Rio de Janeiro and Espirito Santo and large parts of Bahia, Minas, and São Paulo. The map was on a scale of 1 to about 2,500,000. The geologic divisions were: one for fine-grained granite; four for the "terrain primitif"; two for the "periode phylladienne"; one for diorite, and two for the Tertiary. The map and the accompanying sections show a correct acquaintance with local details of the geology at many points, but the generalizations for the large areas embraced are far from correct; nor do they give a clear idea of the general geology.

Alberto Betim Paes Leme, 1912.—In his pamphlet entitled "Os gneisses do Rio de Janeiro," published at Rio de Janeiro in 1912, Dr. Alberto Betim Paes Leme gives a geologic map covering an area of 175 square kilometers in the State of Rio de Janeiro, including part of the city of Rio and the region 18 kilometers to the west of it. The map is on a scale of 1 to 50,000, four divisions of the granitic rocks are shown, and the diabase is put in diagrammatically.

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RIO GRANDE DO NORTE

Previous investigations.—The papers of Branner, Crandall, Jenkins, Soper, and Waring are the only ones that treat of the geology of the State of Rio Grande do Norte. There are a few notes, however, by Koster and Burlamaqui.

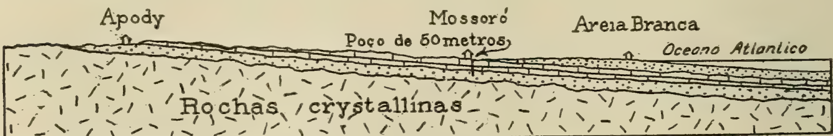

Figure 19.—*Typical Section from the Archean in the Interior to the Ocean on the Coast of Rio Grande do Norte*

R. H. Soper.

General geology.—The interior of Rio Grande do Norte is of Archean rocks; overlapping these old rocks is a belt or zone of Cretaceous and Tertiary marine sediments along the entire coast. This belt varies in

width from about thirty kilometers in the vicinity of Natal and south of there to a width of 130 kilometers about Mossoró. A few remnants of the coastal sediments cap the mountains south of Mossoró, known as Porto Alegre, Martins, and João do Valle.

The Archean rocks are cut by dikes and by quartz veins, and there are patches of old Paleozoic quartzites let down into the Archean rocks by faults.

Economic geology.—The sedimentary belt contains limestones, and there are also occasional crystalline limestones in the Archean areas.

Mica and asbestos are reported from the Archean area, and clays for the manufacture of bricks, tiles, and common pottery are abundant in the coastal sedimentary belt. Sands for the manufacture of common glass are abundant.

Geologic Maps of Rio Grande do Norte

Branner, 1901.—A sketch-map showing the geology of the southern coastal region of Rio Grande do Norte was published, as plate 15 of Branner's paper on the geology of the northeast coast of Brazil, in the Bulletin of the Geological Society of America, volume 13, opposite page 93, 1901. The details of Branner's map at and north of Natal were corrected by Jenkins' map, published in 1913.

R. H. Soper, 1913.—A report made to the Inspectoria do Obras Contra as Seccas by R. H. Soper in 1913, under the title "Geologia e supprimento d'agua subterranea no Rio Grande do Norte e Parahyba" (publication number 26), is accompanied by a geologic map of Rio Grande do Norte. It is on a scale of 1 to 1,000,000 and shows four subdivisions, namely: (1) gneisses, granites, and schists, (2) sandstones, (3) limestone, and (4) sands and clays.

R. H. Soper, 1916.—A paper by R. H. Soper, entitled "The geology of Parahyba and Rio Grande do Norte, Brazil," and published in volume LV of the Proceedings of the American Philosophical Society in 1916, contains a small map showing the geology of that State. It is on a scale of 1 to 2,941,176 and shows four geologic subdivisions, namely: Paleozoic, late Cretaceous to early Tertiary sandstones, late Cretaceous to early Tertiary limestones, and Recent to Tertiary sands and clays.

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RIO GRANDE DO SUL

Previous investigations.—The base map of the State has been constructed from the list of latitudes and longitudes published by Dr. H. Morize, of the Observatorio Nacional at Rio de Janeiro, and from the map of the State "Organizado na Directoria da Viação da Secretaria das Obras Publicas . . . 1907-1911," but without the name of the author.

The literature relating to the geology of Rio Grande do Sul has always been overshadowed by the importance of the coal found in that state. Every writer on the geology has felt it to be his duty to enlarge on or to repeat the oft-repeated descriptions of the coal deposits, coal mines, operations, and exports. The gold and copper deposits have also come in for their share of interest, while the general geology of the state has received but scant attention.

Valuable contributions to the geology of the state have been suggested by the work done in Uruguay by Walther and Guellemain, while the work of Walther in the vicinity of Lavras and Cacipava is among the best papers on the geology of that state.

The work of Dr. F. A. de Vasconcellos Pereira Cabral, done on the coal regions and published in 1851, is not only a valuable contribution to Brazilian geology, but it still stands as an excellent and thoroughly conscientious piece of detailed work at a time when the data obtainable from the coal mines were not available and when there was but little interest in the geology of the state.

Sellow's notes on Rio Grande do Sul are excellent, though they were made in 1823 and in spite of the fact that it is difficult to locate many of

the places mentioned by him. The notes of Sellow and of other geologists give the impression that the region of granites and gneisses south of the trap escarpment contain many infolded or infaulted patches of Permian or other older rocks. With the data now available it is quite impossible to outline these areas.

The paper of Dr. K. Walther, of Montevideo, "Ueber Transgressionen du oberen Gondwana-Formation in Südbrasilien u Uruguay," deals with the geologic history of the State of Rio Grande do Sul and is altogether one of the best papers on the geology of that state.

On the geological map the coastal deposits in Rio Grande do Sul are put down as Quaternary. It is highly probable that some of these deposits are Pliocene, but thus far the paleontologic evidence of their Pliocene age is lacking.

The chief publications on the coal of the state are those of Bem, Cabral, Dahne, Frank, Ginty, Graça, Hull, Lange, Lyon, Parigot, Plant, Pederneiras, Primavera, Thornton, and I. C. White.

Papers on the gold and copper deposits are those of Eddy, Gorceix, Groddeck, Netto, and Walther.

The principal authors who have written on the paleontology of the state are Carruthers, Seward, White (David), Woodward, and Zeiller.

General geology.—Tertiary and Quaternary sediments, inclosing Lagoa dos Patos and Lagoa Merim, form a belt along the coast and lap back against the Archean area. To the landward of this belt lies an area of Archean rocks with here and there outliers of Triassic rocks, and of Lower Permian rocks, in which coal is found. The high land in the northern and western parts of the state is mostly pre-Cretaceous trap resting directly on Triassic beds.

These geologic divisions correspond fairly well with the broad topographic features of thé state. The Archean rocks are charactiristic granites, gneisses, and schists. There are probably some of the older Paleozoic rocks within the Archean area, but they have never been located in detail.

The oldest rocks in the state from which fossils have been obtained are the Lower Permian in which the coal occurs. The rocks of this series are sandstone, shales, and coal beds, all of them somewhat folded.

The Triassic beds are reddish sandstone, approximately horizontal, but broken by many faults, some of them having considerable dislocations. The discovery in these beds of reptilian bones (*Scaphonyx fischeri*) near Santa Maria da Bocca do Monte, in Rio Grande do Sul, made it possible for Dr. A. Smith Woodward to determine their age satisfactorily.

The eruptive rocks that overlie the Triassic in Rio Grande do Sul are

part of a great sheet or of a number of flows that are widely exposed over the Brazilian states of Matto Grosso, São Paulo, Paraná, Santa Catharina, Rio Grande do Sul, and over parts of Uruguay, Paraguay, and the Argentine Republic. The rocks are mostly diabase porphyrite, often amygdaloidal. They appear sometimes as dikes and sometimes as sheets whose margins form steep mountain escarpments.

Siemiradski thinks there are faults with large dislocations through the northern part of the state, but as yet they have not been precisely located.

Economic geology.—The chief mineral products of Rio Grande do Sul is coal, which is found only in the Lower Permian areas. Copper and gold have been mined from the older Paleozoic rocks near Lavras, and large quantities of agates that weather from the trap rocks or are shipped from the plateau region south of Passo Fundo. Marble is reported from several places within the area of the crystalline rocks, and zinc is said to occur, but not in workable quantities (Scott). Magnesite is reported from Rio Pardo and from Rio Capivary, where it occurs in Archean rocks, probably in the form of crystalline marble. It is popularly known at these places as *pedra moura, marmore amarello,* and *olho de boi branco.* Molybdenum is said to occur with copper at Palmas (Oliveira).

Geologic Maps of Rio Grande do Sul

Hettner, 1891.—An article on southern Brazil published by Dr. Alfred Hettner in the Zeitschrift der Gesellschaft für Erdkunde zu Berlin, Band XXVI, Berlin, 1891, contains a sketch-map of the general geology of the State of Rio Grande do Sul. It is on a scale of 1 to 7,500,000 and shows one structural section and five subdivisions of the geology, one of which, the red sandstone, is said to be of undetermined age.

Branner, 1906.—In the first edition of his Geologia Elementar, Rio, 1906, Branner published, at page 238, a sketch-map of the geology of most of Rio Grande do Sul and part of Santa Catharina. The data for it were taken chiefly from Hettner's paper. It is on a scale of 1 to 4,300,000 and five subdivisions of the geology are shown. The same map is given at page 319 of the second edition of Branner's Geologia Elementar, Rio, 1915.

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1 to 2,010,365. The date on the map is 1907, but the report was published at Rio de Janeiro in 1908.

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SANTA CATHARINA

Previous investigations.—Only the eastern half of the State of Santa Catharina has had its geology described. The few papers that treat of its geology confine themselves chiefly to the coal deposits on Rio Tubarão. The most important of these are the publications of Dr. Gonzaga de Campos, of Dr. I. C. White, of Parigot, of E. Dahne, and of Thornton. The works that are most enlightening of all in regard to the geology outside of the coal region are the papers of Dr. J. B. Woodworth and of Euzebio Paulo de Oliveira. Carl Ballod's Der Staat Santa Catharina, in Südbrasilien, also has some helpful notes on the geology.

A meteorite found on the island of São Francisco, in Santa Catharina, has attracted considerable attention among mineralogists. It has been written on by Becquerel, Gonzaga de Campos, Derby, J. L. Smith, Guignet, Calogeras, Damour, Daubrée, Lunay, Meunier.

General geology.—Archean rocks form a belt lying between the ocean and the crest of the Serra do Mar. Except in the north, however, the Archean rocks do not rise quite to the tops of the mountains, but end on their eastern flanks. Resting on the granites are the Lower Permian beds, in which coal is found west of Tubarão. Glacial action in Permian times is shown by these beds near Rio Negro. On top of the Lower Permian are the Upper Permian, on top of which are the Botucatú Triassic sandstones, followed next by sheets and dikes of trap (diabase porphyrite). All of these sediments and the accompanying trap sheets have a general and gentle westward dip, while the traps cover nearly all of the western half of the state.

Economic geology.—The chief mineral resources of Santa Catharina are coal from the mines in the Lower Permian about Minas and the agates found in the areas of the eruptive rocks. Bituminous shales are abundant in the Permian, marble is found in the Archean area, and lead and copper are reported by Dr. Francisco de Paula Oliveira.

Geologic Map of Santa Catharina

I. C. White, 1908.—The only geologic map of Santa Catharina known to the writer is the one given by Dr. I. C. White as part of a map of the States in which coal is found. The scale of the map is 1 to 2,010,365; only two divisions are shown and these not in detail, the Tubarão or Permian coal horizon and the rocks above it. The map is dated 1907, but the report was published at Rio in 1908.

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SÃO PAULO

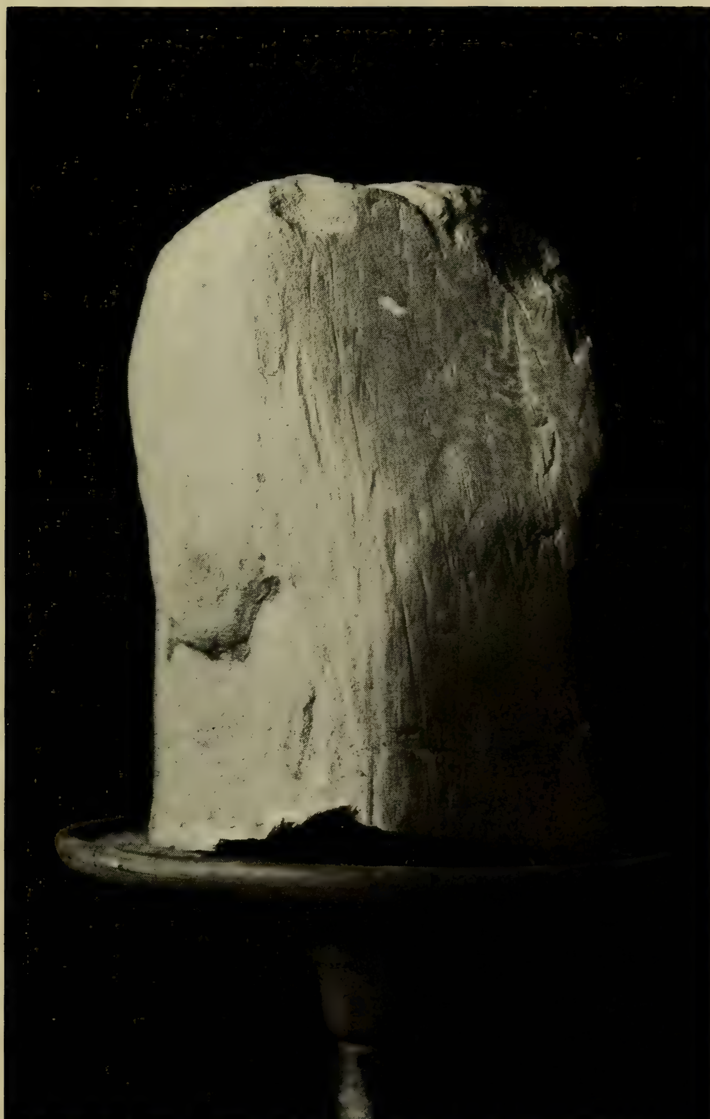
Previous investigations.—The base map used for the State of São Paulo was the one issued in 1912 by the Commissão Geographica e Geologica de São Paulo.

More geologic work has been done in São Paulo than in any other one Brazilian state. As yet, however, no general description of the geology of the state has been published. Mr. Derby, who was state geologist from 1886 to 1904, published many special papers on the geology of the state, the most important of which are mentioned below. The survey (officially called the Commissão Geographica e Geologica de São Paulo) has published five topographic sheets in preliminary editions (Jundiahy, Campinas, São Roque, Rio Claro, Ytú), but only parts of the areas are geologically mapped, while by some unfortunate oversight the names of the geologists who did the work are not given. Several large folios have been issued, but they are devoted to the explorations of some of the larger streams of the state—the Tieté, Feio, Aguapehy, and Rio Grande. These folios are fully illustrated by beautiful photographs. A few of them contain short papers with notes on the geology, but the publications are too unwieldly to be used in the field. One by Dr. Florence, on Rio Grande, is especially valuable on that region, and the paper by Pacheco, on the fossils found in the Baurú beds, is of great value as determining the age of that formation. The geology along the Paranapanema is described by Dr. Francisco de Paula Oliveira in a bulletin published by the survey.

Two papers by Dr. Gonzaga de Campos are especially valuable contributions; they are (1) Baurú e Itapurú, and (2) Relatorio sobre o Rio Tieté.

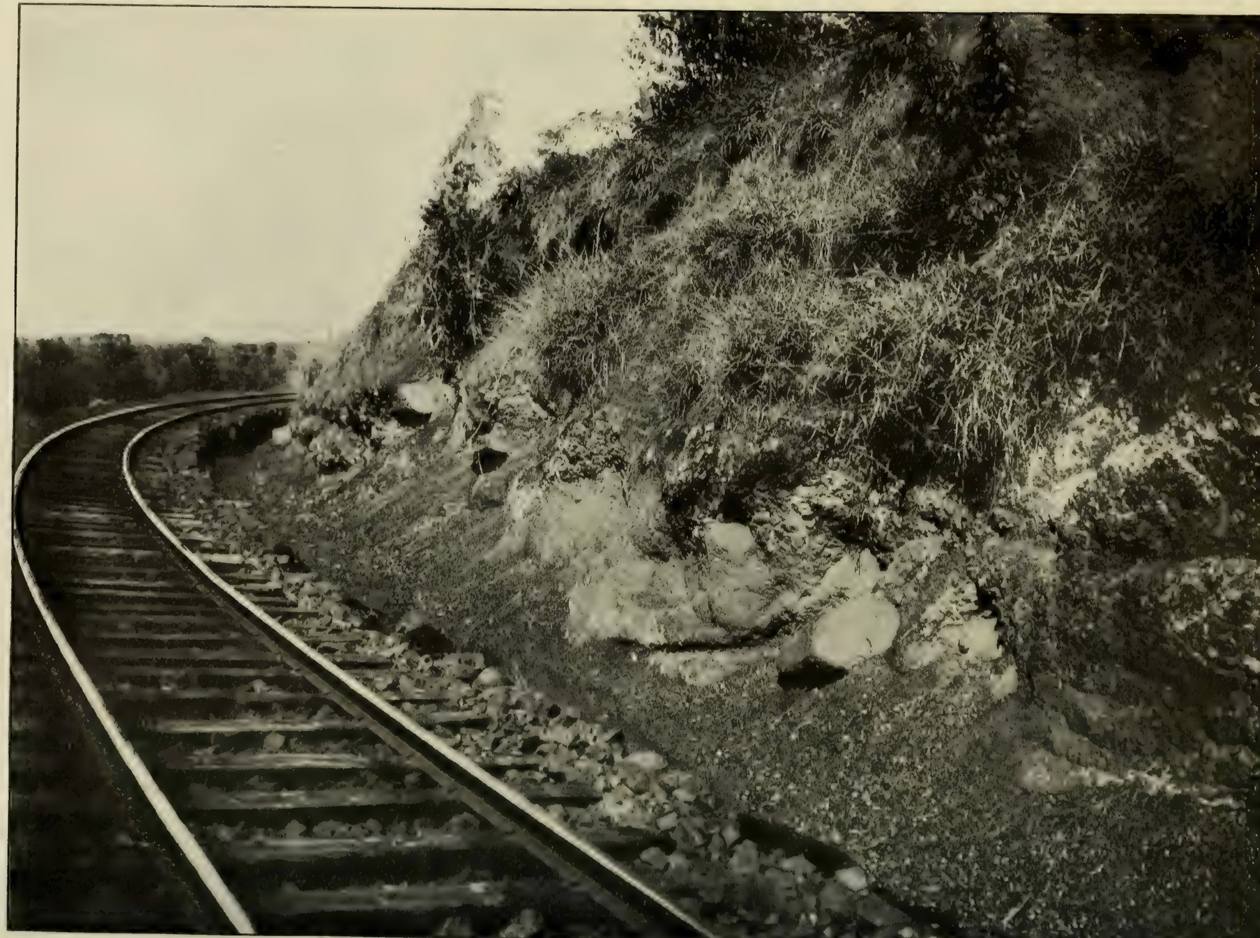
The iron deposits of the state are described by Derby; the Permian glacial deposits are briefly described by J. B. Woodworth, and the fossils are described by Cope, Geinitz, Pacheco, Renault, Von Ihering, and Woodward.

General geology.—Over the eastern and southeastern parts of the State of São Paulo are exposed the Archean rocks which form the Serra do



STRIATED BOULDER OF QUARTZITE FROM THE PERMIAN BEDS NEAR MOCOCA, STATE OF SAO PAULO

Size, 7.5 by 5 centimeters. Commissão Geologica de São Paulo.



PERMIAN TILLITE BEDS CONTAINING GLACIATED BOULDERS

The location of this area is kilometer 190, Mogyara Railway, State of São Paulo, between stations Coronel Correa and Baldeação. Dr. G. Florence, 1913.

Mar and pass over the divide and extend westward to the base of the Lower Permian sediments. In the southwest corner of the state a small exposure (70 kilometers long) of Devonian rocks rests against the Archean and dips gently toward the northwest. On top of the Devonian rocks are Lower Permian beds—sandstones and shales—which rest on the Archean from near Faxina to the Minas frontier just north of Mococa, São Paulo. These Lower Permian beds contain well marked evidences of glaciation. The next higher beds are the Upper Permian, which contain the fossils *Stereosternum* and *Mesosaurus* and characteristic siliceous concretions and beds. The Permian beds are followed by the Triassic red beds called the Botucatú. They form the mass of the Serra de Botucatú and extend southwestward into the State of Paraná and northward to and beyond Rifaina, where they cross into the State of Minas. Still farther west, and forming the highlands of a large part of the state, are the Baurú beds, which are Lower Cretaceous. These sedimentary beds dip gently toward the northwest. All beds below the Baurú (Cretaceous) are cut by eruptive dikes, and the Triassic sediments are interbedded with sheets of lava. In showing the areas of the eruptive rock on the São Paulo part of the geologic map no attempt is made to give the details of the areas, partly because the areas have not been outlined and partly because the scale of the map does not admit of such details. The red lands of São Paulo, famous for their fertility, are formed by the decomposition of the eruptive rocks, and the areas of the red lands are really much larger than the map might lead one to suppose.

From 30 kilometers west of the city of São Paulo and following down the Rio Parahyba to Bocaina, there are bituminous shales and sandstones marking the sites of Tertiary lakes within the Archean area.

Economic geology.—The mineral resources of São Paulo now known are iron, marble, bituminous shales, building stones, limestones, and ceramic clays.

The first iron manufactured in Brazil, and probably the first made in America, was produced about the year 1600, at Ipanema, in the State of São Paulo. The manufacture of iron at that place was not kept up, and though it was attempted several times afterwards, it has thus far never been commercially successful.[81] The Ipanema iron ores are in an isolated Archean area, a little more than a hundred kilometers west of the city of São Paulo.

The bituminous shales at the base of the Upper Permian are exposed at many places in São Paulo and could easily be located along nearly all

[81] Leandro Dupré: Memoria sobre a fabrica de ferro de São João de Ipanema. Annaes da Escola de Minas, no. 4, pp. 49-90. Rio, 1885.

of the outcrop of those beds. So far as I can learn, they have not been utilized. These shales have been regarded as evidences of the existence of petroleum, and wells have been sunk in search of it, but thus far without success. The bituminous shales of the Tertiary lake deposits, however, have been used at Taubaté for the manufacture of gas. They contain about 7 per cent of petrolene.

Marbles occur in large quantities at certain places in the Archean areas of the state, notably in the region about the headwaters of the rios Iporanga and Bethary west, northwest, and north of Villa Iporanga, and at Pantojo west of São Roque and south of Sorocaba, where there are extensive quarries. There are also limestones in the Permian areas, notably at Limeira, Itapetininga, and, in addition to the marbles mentioned, building stones of many kinds are abundant and of excellent qualities.

Clays for the manufacture of bricks, tiles, and drain and sewer pipes are especially abundant in the Tertiary areas of the state.

Geologic Maps of São Paulo

Pissis, 1842.—Accompanying Pissis' "Mémoire sur la position géologique des terraines de la partie australe du Brésil," published by the French Academy in 1842, is a geologic map that includes the eastern part of the State of São Paulo as far west as Piracicaba. The scale is 1 to 2,500,000 and ten divisions are shown, one of which is the Tertiary lake basins of that state.

Derby, 1885.—An outline of the geology of eastern São Paulo by O. A. Derby is given in a map accompanying C. F. Van Delden Laerne's "Le Brésil et Java; Rapport sur la culture du café en Amérique, Asie et Afrique. La Haye, 1885." The map bears the date 1884; it is on a scale of 1 to 1,000,000 and shows six geologic divisions.

The same map, with a few additions, was reproduced in Branner's Geologia Elementar, at page 230 of the first edition, 1906, and at page 320 of the second edition, 1915. The scale of the reproduction is about 1 to 5,000,000 and five geologic divisions are shown.

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A. SMITH WOODWARD: On a tooth of a Triassic Dinosaur from São Paulo, Brazil. Report of the British Association for the Advancement of Science for 1909, page 483, 1910.

J. B. WOODWORTH: Geological expedition to Brazil and Chile—1908-1909. Bulletin of the Museum of Comparative Zoology, volume LVI, number 1, 8°, illustrated, 135 pages. Cambridge, Massachusetts.

R. ZEILLER: Sur un Lepidodendron silicifié du Brésil. Comptes Rendus de l'Academie des Sciences, volume CXXVII, pages 245-247. Paris, 1898.

SERGIPE

Previous investigations.—Hartt's Geology and Physical Geography of Brazil contains the first valuable notes on the geology of the State of Sergipe. The general geology of the state was described later in Branner's paper on the geology of the Sergipe-Alagôas basin. That paper was translated into Portuguese and published at Aracajú in 1899. The last important contribution is that of R. H. Soper, whose report is mentioned in the accompanying bibliography. Our knowledge of the geology of that state was also contributed to by Roderic Crandall, who, as my assistant, first outlined the geology of the interior of the state in 1908.

Cretaceous fossils are abundant in the State of Sergipe. The paleontology of the state is described in Dr. Chas. A. White's important "Contributions to the Paleontology of Brazil," published as volume VII of the archives of the Museu Nacional of Rio de Janeiro in 1887.

General geology.—Though Sergipe is a small state, its geology is remarkably comprehensive, and, on account of the accessibility of the rocks and their fossils, it affords the key to the geology of a large part of Brazil. The sequence of the rocks may be seen in the Serra Itabaiana and its prolongations, from the Archean area about the village of Itabaiana to the Tertiary beds near the seacoast. The ages of all of the rocks have not yet been determined with certainty, but it is known that they include representatives of Archean, Paleozoic, Mesozoic, and Cenozoic beds, some of them known to be fossiliferous. The Archean area of the state lies along the Rio São Francisco from just above Penedo to above the falls of Paulo Affonso. The Serra Itabaiana is a monoclinal ridge of quartzites resting on the Archean rocks and dipping eastward toward the ocean. Above the quartzites are limestones, shales, and sandstones that continue up into and through the Upper Cretaceous. Still higher horizontal sedi-

ments near the coast are Tertiary. West of the Serra Miaba is an area of limestones and shales; the Cretaceous series about Maroim and Larangeiras also contains large areas of limestones.

Economic geology.—The limestones and clays of the state are very abundant, are available for the manufacture of Portland cement as well as for ordinary lime, and the oolitic limestones on Rio Sergipe would make excellent building stones. At present those rocks are not used save for the manufacture of small quantities of lime for local consumption. The cream-colored flaggy limestones exposed along Rio Cotinguiba at Sapucary have long been used locally for foundations and for walls and street pavements.

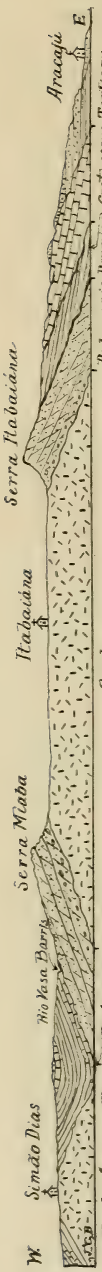

FIGURE 20.—Section across the State of Sergipe from Simão Dias to the Ocean

The distance is 100 kilometers.—Branner and Soper.

Geologic Maps of Sergipe

Branner, 1913.—An article by Branner on the Estancia beds of Bahia, Sergipe, and Alagoas, published in the American Journal of Science, volume 35, for June, 1913, page 619, was accompanied by a small map showing the geology of the southwestern part of the State of Sergipe. It is on a scale of 1 to 2,500,000 and shows three subdivisions, namely: crystalline complex, Permian, and Cretaceous and Tertiary—the last two as one.

Soper, 1914.—A geologic map of Sergipe was published by R. H. Soper in his "Geologia e supprimento d'agua subterranea em Sergipe," etcetera, publication number 34 of the Inspectoria de Obras Contra as Seccas, Rio de Janeiro, July, 1914. It is on a scale of 1 to 1,000,000 and shows four geologic subdivisions, namely: pre-Cambrian, Paleozoic, Permian (?), Cretaceous and Tertiary—the last two as one.

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FELISBELLO FIRMO DE OLIVEIRA FREIRE: Historia de Sergipe, 1575-1855. Rio de Janeiro, 1891. Caput IV, paginas lii-lxvi, on the geology, is a résumé from Liais and Hartt.

CH. FRED. HARTT: Geology and physical geography of Brazil. Maps and Illustrations, xxiii + 620 pages. Boston, 1870. Sergipe, at pages 378-426.

ALPHEUS HYATT: Report on the Cretaceous fossils from Maroim, Province of Sergipe, Brazil. Hartt's geology and physical geography of Brazil, pages 385-393. Boston, 1870.

ALPHEUS HYATT: Pseudoceratites of the Cretaceous. Monograph XLIV, U. S. Geological Survey, Washington, 1913. *Vascoceras Harttii* from Sergipe, page 103, plate XIV.

R. H. SOPER: Geologia e supprimento d'agua subterranea em Sergipe e no nordeste da Bahia. Publicação no. 34 da Inspectoria de Obras contra as Seccas. Rio de Janeiro, 1914. 100 paginas e carta geologica.

CHARLES A. WHITE: Contribuições á Paleontologia do Brazil (com o original em inglez), Archivos do Museu Nacional. Volume VII, 4°, paginas 1-273, and 28 plates. Rio de Janeiro, 1887. 350 copies of this report were issued as a special edition, dated Washington, January 21, 1888, under the title: "Contributions to the paleontology of Brazil; comprising descriptions of Cretaceous invertebrate fossils mainly from the provinces of Sergipe, Pernambuco, Pará, and Bahia. By Charles A. White."

OUTLINES OF THE ECONOMIC GEOLOGY

GENERAL OBSERVATIONS

It is not my purpose to go into details in regard to the economic geology of Brazil. For the use of those who may be interested in this particular branch of the subject, a list of the principal mineral resources of Brazil is given below. It should be clearly understood, however, that this list of minerals of economic importance does not pretend to be complete. For example, the statement that the principal known iron deposits are those of Minas, Matto Grosso, and São Paulo is not meant to imply that iron does not occur in the other states. It must be constantly kept in mind that the geology of Brazil is incompletely known, and much remains to be done in order to disclose all of the mineral resources of the country. New mineral resources are being discovered from time to time, and it is reasonable to believe that Brazil will in time greatly increase the number of her mineral products.

The list of minerals mentioned below must therefore be regarded as only tentative and subject to change in accordance with any facts that may come to light and to developments that may be made. On the other hand, it is one's duty to distinguish between the simple occurrence of a

mineral and its availability for commercial and industrial purposes. In regions of highly metamorphosed rocks like those of Minas Geraes, Goyaz, parts of Bahia, etcetera, it is to be expected that a long list of minerals should be found, though many of them do not occur in sufficient abundance to give them economic importance, in so far as we now know.

There are no comprehensive works on the general economic geology of Brazil; but a somewhat remarkable work and one well worth knowing, if used with discrimination, is the "Diccionario Geographico das Minas do Brazil, por Francisco Ignacio Ferreira," published at Rio de Janeiro in 1885. It is mostly a compilation of all the available information regarding the mineral resources, whether real or imaginary, published or unpublished, of each of the Brazilian states, and alphabetically arranged. It contains many notes of value and excerpts from the leading authorities, but it also and necessarily contains much that is worthless or misleading. For example, every state and almost every municipality is said to contain coal, even in the most impossible locations. Of course, the author of the work is not responsible for such claims.

A book of 161 pages, by Dr. Antonio Olyntho dos Santos Pires, entitled "Riquezas Mineraes," published at Bello Horizonte in 1903, gives a good, though brief, historical résumé of the mining industry.

Since the above was written a valuable work has been published, "The Mineral Deposits of South America," by Benjamin L. Miller and Joseph T. Singewald, Jr., New York, 1919. Chapter V, pages 148 to 232, of this book, is upon the economic geology of Brazil, and is accompanied by a brief bibliography.

METALLIC MINERALS *

Iron.—Extensive iron deposits of excellent quality—mostly hematite, but including magnetite, ochres, and other forms of iron ore—are known in Minas Geraes, São Paulo, Matto Grosso, Goyaz, and Bahia. An important résumé of the manufacture of iron in Brazil is given in the paper on the subject by Dr. Gonzaga de Campos, director of the Geological Service of Brazil. So far as we now know, the high grade ores are confined to the early Paleozoic, but there are large areas of lower grade ores in the Tertiary and Quaternary. The history of the attempts at ironmaking at Ipanema, São Paulo, is given by L. Dupré. The most comprehensive papers on the subject of iron in Brazil are those of—

* In order to use the papers cited by authors under the heads of the various minerals, the reader should find the full titles under the author's name as given in the bibliographic references of each state. For example, Lisboa (Matto Grosso) means that under Matto Grosso the full title of Dr. Lisboa's paper will be found.

Bello (Minas)	Leith and Harder (Minas)
Bovet (Minas)	Lisboa (Matto Grosso)
Calogeras (São Paulo)	Porto Seguro (Minas)
Campos	Richards (Minas)
Derby (Minas)	Schüch (Minas)
Dupré (São Paulo)	Scott (Minas, etcetera)
Ferrand (Minas)	Sena (Minas)
Gorceix (Minas)	Silva (São Paulo)
Graça (São Paulo)	Thiré (Minas)
Harder and Chamberlin (Minas)	Wetter (São Paulo)
Kidder (Travels)	

Gold.—Gold has been mined in almost every state in Brazil, but the principal producing states are Minas Geraes, Matto Grosso, Goyaz, and Bahia. Though Brazil was at one time the greatest gold-producing country in the world, there are now but few rock mines in that country, and those are all in the State of Minas Geraes. A great deal that has been written on the subject has but little or no scientific value. The most important papers are by the following writers:

Berg (Minas)	Jacob, R. (Minas)
Böhner (Minas)	Katzer (Pará)
Bovet (Minas)	Kitto (Minas)
Brazilian Review (Minas)	Levat (Pará)
Costa (Bahia)	Monchot (Minas)
Cumenge, E. (Minas)	Netto (Rio Grande do Sul)
Eschwege (Minas)	Porto Seguro (Minas)
Ferrand (Minas)	Schwerin (Minas)
Gorceix (Minas, Rio Grande do Sul)	Scott (Minas)
Groddeck (Rio Grande do Sul)	Sena (Minas)
Hussak (Minas, Goyaz)	Tavares (Minas)
	Touzeau (Minas)

Silver.—Silver is occasionally reported, but in all cases of which I have any knowledge it occurs with lead in the form of argentiferous galena. (See José P. X. da Veiga, Revista do Archivo Publico Mineiro, volume II, pages 757-765. Ouro Preto, 1897.)

Copper.—Copper is known in Bahia, Ceará, Rio Grande do Sul near Lavras, and in Matto Grosso, and it has been found in small quantities in Minas Geraes near Ouro Preto and Sete Lagoas and in Santa Catharina. The copper ores are mostly in rocks of the Brazilian complex.

The principal papers on copper in Brazil are those of Branner on Bahia, Gorceix, Groddeck, Netto, Scott and Walther on Rio Grande do Sul, Hussak on São Paulo, Small on Ceará, and Vandelli.

Zinc.—Zinc has been found in Minas, but, so far as I have learned, never in commercial quantities (Sena). A little is also found in the

gold mines of Rio Grande do Sul (Scott). It occurs in rocks of Archean age.

Lead.—Lead is found at Abaeté, in the western part of the State of Minas Geraes, where attempts were made to mine it in 1800, in 1812, in 1825, and again in 1880, but thus far without success. It has also been found in a few other places in Minas and in São Paulo, Maranhão, Santa Catharina, and Rio Grande do Sul, but it has never been successfully worked.

Groddeck (Rio Grande do Sul)
Oliveira (Minas and Santa Catharina)
Souza (Maranhão)
Veiga (Minas)

Tin.—Tin has been found in the northern part of Minas, but only as mineral specimens. It is also said to occur in São Paulo near Batea and Antonio Ficou.*

Manganese.—Although Brazil only began the exportation of manganese in 1894, since the year 1896 she has been one of the three greatest producers of manganese ore in the world. The deposits thus far worked are in Minas Geraes and Bahia. Newly discovered deposits have been opened lately on the lands of the Saint John del Rey Mining Company near Morro Velho in Minas, and in the Jacobina mountains near Bomfim in Bahia. Lisboa reports important deposits in Matto Grosso. All of the valuable deposits are in either early Paleozoic or Archean rocks.

Beck (Minas)
Bellet (Minas)
Birkenbine (Brazil)
Branner (Bahia)
Camara (Bahia)
Costa (Minas)
Demaret (Brazil)
Derby (Minas)
Dieseldorf (Minas)
Friz (Minas)
Furniss (Bahia)
Greven (Minas)
Harder (Minas)
Hussak (Minas)
Katzer (Pará)
Koeller (Brazil)
Lisboa (Brazil)
Lustosa (Minas)
Michaeli (Minas)
Oliveira (Minas)
Pires (Minas)
Rocha (Minas)
Rizzini (Bahia)
Sampaio (Bahia)
Scott (Minas)
Singewald (Minas)
Thomas (Minas)
Wigg (Minas)

* J. C. da Costa Sena: The occurrence of tin in Minas Geraes. Brazilian Mining Review, vol. i, pp. 92-93, Rio de Janeiro, July, 1903, and Annaes da Escola de Minas number 6, pp. 5-11. Ouro Preto, 1903.

João Pedro Cardoso: Relatorio da Commissão Geographica e Geologica de São Paulo para o anno de 1906, p. 25. São Paulo, 1907.

Nickel.—Nickel in the form of garnierite, the hydrous silicate of magnesium and nickel, is known near Livramento, in southern Minas Geraes, in rocks of either Paleozoic or Archean age.*

Chromium.—Chromium is not worked at present in Brazil, but it is probable that it occurs in considerable quantities in connection with the serpentines of Bahia, Minas, etcetera. Williams reports it from Livramento, Minas.

Platinum.—Platinum has long been known from Minas Geraes, but, so far as I have been able to learn, no effort has been made to work it. It appears as sands in connection with the diamond-bearing alluvial deposits, and in the auriferous iron sands of Gongo Soco and of Itabira do Matto Dentro and on Rio Abaeté, in the State of Minas Geraes. Claussen says it is found also at Itambé (Notes géologiques, page 9) and elsewhere in the terrain "traumeteux." The best paper is that of Hussak, an abstract of which is given in the American Journal of Science, fourth series, volume XIX, pages 397-399, 1905.

Boussingault (Minas)
Gehlen
Humboldt
Hussak (Minas)
Lampadius
Svanberg (Analyses)
Wollaston

Palladium.—Palladium from Brazil is treated of by Lassaigne, Seamon (Minas), Wollaston, and Hussak (Minas). The most comprehensive paper is that of Hussak in the Sitzungsberichte of the Vienna Academy, Abtheilung I.

Aluminum.—See *Bauxite* under non-metallic minerals.

Tungsten.—Tungsten is reported from Espirito Santo and Minas Geraes by Fr. Freise, Zeitschrift der Praktische Geologie, volume XVIII, pages 143-146, Berlin, 1910. The tungsten minerals stolzite and raspite also occur in Minas, but so far as now known only as mineral curiosities. Tungsten is likely to be found anywhere within the area of the granites and gneisses.

Mercury.—Cinnabar is said to have been found in Minas near Ouro Preto and at Tripuhi and Tres Cruzes. (See Hussak, Machado, and Oliveira.)

Molybdenum.—Francisco de Paula Oliveira reports molybdenum from Rio de Janeiro on the road from Rio to Petropolis, in Paraná, on Rio Capivary 30 kilometers from Curytiba, and at Bahú, 42 kilometers from Itajahy in Santa Catharina, and associated with copper at Palmas, Rio

* H. E. Williams: Nota sobre a occurrencia de um mineral de nickel perto da Villa de Livramento . . . Minas Geraes. Boletin do Ministerio da Agricultura, vol. v, no. 1, pp. 21-28. Rio de Janeiro, 1916.

Grande do Sul. Its association with granitic rocks leads to the inference that it is to be looked for throughout the Archean area of Brazil. (Francisco de Paula Oliveira: A Molybdenita. Curytiba, 1906.)

NON-METALLIC MINERALS

Coal, lignite, and peat.—The known coal deposits of Brazil are confined to the States of Paraná, Santa Catharina, and Rio Grande do Sul, where it occurs in beds of lower Permian age. The mines have long been worked in Santa Catharina and Rio Grande do Sul. In Minas lignites are found in the Tertiary lake deposits. Lignite occurs over a wide area in the Tertiary beds of the western part of Amazonas. See under "Amazonas." Peat is known near Campos, in the State of Rio de Janeiro. Brazilian coal is high in sulphur, but recent experiments show that it can be successfully used on locomotives in pulverized form.*

A full list of references to coal in Brazil is given at pages 287-300 of I. C. White's Report on the Coal Measures and associated rocks of south Brazil, published in English and Portuguese, xxviii + 617 pages, 4°, illustrated, Rio de Janeiro, 1908.

Campos, Gonzaga de	Jordão	Oliveira, P. J. (Bahia)
Dahne	Katzer	Peckenham
Ginty	Koeller	Parigot
Gorceix (Minas)	Machado (Minas)	Pederneiras
Grateau	Macedo	Plant
Graça	Meers	Rechsteinn
Guignet	Murray	Santos
Holmes, J. A.	Oliveira, E.	Souza
Hull	Oliveira, F. de P.	Thornton
		White, I. C.

Petroleum and oil shales.—Up to the present time petroleum has not been found in paying quantities in Brazil. Petroliferous shales, however, have been reported from Alagoas, Bahia, Ceará, Goyaz, Maranhão, Minas Geraes, Paraná, Santa Catharina, São Paulo, Rio de Janeiro, and Rio Grande do Sul. They are found from the Permian to the Pliocene. The most important papers thereon are those of—

Bertrand (Ceará)	Oliveira, E. de
Branner (Alagoas)	Redwood and Topley (Alagoas)
Burke (peat)	Tassart (Brazil)
Campos (São Paulo)	Valentine
Gautier (São Paulo)	Villa Franca (Peat, Campos)
Gorceix (Minas and Goyaz)	White, I. C.
Lisboa (Maranhão)	

* Arrojado Lisboa: O problema do combustivel nacional. Rio, 1916.
A. V. Adamson: Bul. 144, American Institute of Mining Engineers, December, 1918. p. 1773.

Asphalt.—Asphalt has been found in the Permian in Paraná, but it has not been worked. It is also said to exist in the Serra do Bufete in São Paulo, where it impregnates sandstone (Euzebio Paulo de Oliveira and I. C. White).

Building stones.—The building stones most extensively used in Brazil are the granites, which occur over large areas, wherever the Brazilian complex forms the surface rocks. The quarries of Rio de Janeiro are famous for their beautiful granites and gneisses.

Marble.—Marble occurs in great abundance in Bahia, Ceará, Espirito Santo, Matto Grosso, Minas Geraes, Parahyba, Pernambuco, Rio de Janeiro, Rio Grande do Norte, Rio Grande do Sul, São Paulo, and Santa Catharina. Stratigraphically, marbles extend from the Archean to the Cretaceous.

Limestone.—Limestones other than marbles are abundant in Pará, Ceará, Rio Grande do Norte, Parahyba, Pernambuco, Sergipe, Bahia, Minas Geraes, São Paulo, Paraná, Goyaz, and Matto Grosso. Stratigraphically, they extend from the Archean to the Tertiary. At many places they might readily be used for the manufacture of Portland cement.

Gypsum.—Wells reports a cliff of satin-spar 60 feet high on Rio Grajahú, State of Maranhão, a few kilometers down stream from the port of Chapada.[82]

Anhydrite.—Anhydrite is reported in Minas Geraes near Sabará (Liais, Géologie, 139).

Magnesite.—Magnesite is reported from Archean areas at Rio Pardo and Rio Capivary, in Rio Grande do Sul, but it may be expected in Bahia and Minas and in connection with the serpentines and dolomites, wherever they occur in Brazil—usually in the Brazilian complex. Information available about the magnesite of Rio Grande do Sul is very meager.

Kaolin, clay, fullers earth.—Kaolin is found at many places where the feldspathic rocks of the Brazilian complex are deeply decomposed: Minas, Espirito Santo, Rio de Janeiro, etcetera. There is an important ceramic factory at Caethe, in Minas, where the local clays are used.[83]

Glass sands.—Glass sands are abundant here and there along the coast of Brazil from Espirito Santo northward to the mouth of the Amazon. There are some noteworthy deposits near the mouth of Rio Formoso, State of Pernambuco. These sands are usually Quaternary or Recent.

[82] J. W. Wells: Three thousand miles through Brazil, vol. ii, p. 268.

[83] Cypriano J. Carvalho: Ceramica Nacional fundada em Caethé, Estado de Minas, pelo Dr. João Pinheiro. Revista Industrial de Minas, vol. iii, pp. 213-218, 15 de Agosto e 15 de Setembro de 1896.

Asbestos.—Asbestos has been found in Bahia, where it is associated with serpentines, and from Santa Luzia, State of Minas. There is said to be a deposit at Taquaral near Ouro Preto and one near Caethe, at a place called Retiro. (Francisco de Paula Oliveira: Revista Industrial de Minas Geraes, volume I, page 15, October, 1893.)

Talc.—Talc occurs in large quantities in the old metamorphic rocks of the Brazilian complex in Bahia and Minas Geraes, and probably in many other states, in association with the crystalline rocks. It has long been used locally for making certain cooking utensils, but otherwise it is not used at present.

Mica.—Mica is known to occur in São Paulo at Juquiá, Goyaz, Espirito Santo, Minas Geraes (at Bicas, and near Manhuassu, near Santa Luzia de Carangola, and at Fonseca), Rio de Janeiro near São Fidelis, Sergipe and in Bahia east of the Serra de Jacobina, and near the falls of Paulo Affonso. It is to be expected in pegmatite dikes in all states within the area of the crystalline rocks.*

Salt.—Salt is common in the dry or semi-arid limestone regions of the interior. Before the days of railways, large quantities of salt were manufactured in the interior, but its manufacture is now almost abandoned, on account of the facilities for obtaining it elsewhere and the better quality to be had from the seacoast. The salt made in the interior is produced by leaching the efflorescence and earth from dry lake beds and then evaporating the water thus obtained. Places noted for the former manufacture of such salt are the Salitre Valley, in Bahia; Rio Mosquito, in Minas near Grão Mogol, and elsewhere in the limestone areas of the Rio São Francisco and Goyaz. So far as I have been able to learn, no beds of rock-salt in place are known in Brazil. In the valley of the São Francisco the salt seems to have some definite relation to the Permian limestones, but as yet it is not clear what that relation is.

Niter.—Niter deposits are often mentioned as Quaternary and Recent cave deposits. They are found in the caves of all parts of Brazil, notably in the States of Ceará, Pernambuco, Bahia, Espirito Santo, Minas Geraes, and Matto Grosso.

The industry is an uncertain one, and under ordinary circumstances the output is used only for the local manufacture of gunpowder. It is capable of considerable development.

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* João Pedro Cardoso: Relatorio da Commissão Geographica e Geologica de São Paulo, anno de 1907.

H. K. Scott: On the occurrence of mica in Brazil. Transactions of the Institute of Mining and Metallurgy, vol. xii, pp. 351-364. London, 1902-3.

Couto (Minas)	Prates (Minas)
Miranda (Minas)	Silveira (Minas)

Some of the leucite-bearing rocks of Brazil may yet become available for the manufacture of potash. Foyite containing 8.78 per cent of potash (K_2O), and leucite-tinguaite containing 8.86 per cent of potash, are found in the Serra do Tinguá in the State of Rio de Janeiro; leucitophyre, with 8.12 per cent, is found at Poço de Caldas, and leucite granite porphyry, with 8.80 per cent of potash (K_2O), is found on Rio Pardo in the Serra de Caldas. The last two places are in southwestern Minas Geraes.

Graphite.—Graphite is found in Archean rocks in Minas near São Miguel[84] and about Minas Novas, but it is not known to have been mined. It is reported near Abrantes, northeast of Bahia. Freise reports it from Espirito Santo and Wells reports it from east of Chapada, in the State of Maranhão.[85] It seems to be confined to the areas of the Brazilian complex.

Bauxite.—Bauxite has been found in southwestern Minas, in the vicinity of Poço de Caldas, where it is derived by decomposition from alkaline igneous rocks. Doctor Lisboa reports it in the State of Maranhão. It occurs in the form of sedimentary deposits along some of the tributaries of the lower Amazon River, in the State of Pará. It has not yet been worked anywhere in Brazil.

Later discoveries made in Minas lead to the reasonable expectation that extensive beds may yet be found in Brazil. See under Minas Geraes.

Monazite.—The monazite deposits of Brazil have been known and worked only since 1888. They occur as beach sands that have been washed directly from Tertiary sediments that were derived originally from the underlying crystalline rocks of the Brazilian complex where it is a wide-spread rock constituent. The deposits that are worked are along the beach in the vicinity of Prado, State of Bahia, and on the coast of Espirito Santo north of Victoria. In the first volume of his "Minas do Brasil e sua legislação, Dr. João P. Calogeras gives a good résumé of the subject at pages 447-477 and adds a brief bibliography.

Bohm	Bulhões	Derby
Britto	Calogeras	Furniss
Gorceix	Medrado	Richardson
Hussak and Reitinger	Murtinho	Uhlig
Lisboa	Praguer	

[84] J. C. da Costa Sena: Annaes da Escola de Minas, vol. ii, 1883, pp. 125, 129.
[85] J. W. Wells: Three thousand miles, etc., vol. ii, p. 260.

Zirconia.—The oxide of zirconia, which has been exported from Brazil in considerable quantities within a few years past, is derived by decomposition from nepheline syenites and other kindred rocks. The material was first found as water-worn pebbles in stream beds and as angular fragments scattered over the ground in the vicinity of the nepheline rocks from which they were derived. These rocks are found in the vicinity of Caldas, in the State of Minas Geraes, and near Franca and Jacupiranga, in the State of São Paulo. It is probable that this mineral may occur in other places in Brazil where there are nepheline syenites. They are known at present at Cabo Frio, Campo Grande, Itatiaia, and the peak of Tingua, State of Rio de Janeiro, and they probably occur at many other places in Brazil. (See Derby on the nepheline rocks of Brazil, and E. Hussak and J. Reitinger on zirconia, Groth's Zeitschrift für Krystallographie, 1903, volume 37, pages 550-579.)

Phosphates.—The island of Fernando de Noronha, off the northeast coast of Brazil, is the only place that is known to produce phosphate rock. It is found there as a Recent or Quaternary deposit, on the small island known as Ilha Rapta. A few cargoes are said to have been shipped, but the lack of landing facilities is said to have prevented the establishment of an export business.

Papers have been published on the subject by Bovet, Derby, Lasne, Sena, and Sobragy.

Diamonds.—Diamonds have been mined in Minas Geraes, Matto Grosso, Bahia, and Paraná. The diamond-mining industry of Brazil declined greatly after the discovery of diamonds in South Africa, but it is still conducted on a small scale. Most of the diamonds found in Brazil have been taken from existing stream channels, or from old stream deposits where they have been concentrated by natural processes from the rocks of the surrounding region. Specimens have occasionally been found imbedded in the hard rocks, usually in gravels cemented by iron and evidently not in place, but they have also been found in Paleozoic quartzites. Much has been written upon the origin of the Brazilian diamonds, but, whatever their remote origin may have been, they have thus far been found in paying quantities in Brazil only in stream channels or other deposits formed by concentration. In Paraná they appear to be derived from a Devonian basal conglomerate. In Bahia they come from pink quartzites tentatively referred to the Carboniferous. At Grão Mogol, in northern Minas, they also occur in quartzites. The minerals associated with diamonds in Brazil suggest that their genetic relations are with deep-seated granites, metamorphics, and pegmatites rather than with eruptives. In the State of Bahia, at least, no eruptive rocks

are known in the neighborhood of the diamonds, except at a single place where a small diabase dike breaks through the diamond-bearing quartzites without affecting perceptibly the surrounding rocks. In spite of their great economic importance, there has never been any systematic work done on the geology of the diamonds of Brazil, and, as Calogeras well remarks, "presque tous les gisements diamantiferes du Brésil ont eté découverts par hazard." [86]

From private sources I have lately heard reports of the discovery of diamonds at several places in the State of Minas Geraes in peridotite pipes similar to those in which diamonds occur in South Africa. These reports require confirmation.

Bovet	Galvão	Limonosoff
Boutain	Gorceix	Martius
Boué	Glocker	Mawe
Bensaude	Haidinger	Moissan
Branner	Helmreichen	Nusser-Asport
Campos	Heusser u. Claraz	Oliveira, F. de P.
Castelnau	Hocheder	Oliveira (Salobro)
Claussen	Heuland	Pereira
Cugnier	Hussak	Pires (Ant. O)
Damour	Jacob and Chartrain	Porcheron
Dawson, T.	Jannetaz	Praguer
Dié	Jardim	Rezende
Dennis 2	Jeremejew	Rivot
Derby (Paraná)	Kunz	Schwartz (Bahia)
Dieulafait	Lawrence	Silva (Bahia)
Dufresnoy	Lindsay	Vandelli
Engelhardt		

Carbonados, or black diamonds.—Carbonados are only found in considerable numbers in the State of Bahia, where they are associated with ordinary diamonds.[87] Like diamonds, they are found in stream beds and in old stream deposits, but they have been derived directly from quartzites. The rocks of the surrounding region from which the carbonados have come are all gently folded, false-bedded, pinkish quartzites, and wherever these quartzites have softened by weathering, the miners have broken them up and washed them for the carbonados thus set free. These carbonado-bearing rocks are possibly of Carboniferous age, but no fossils have yet been found in them and their age is therefore in doubt. The region of the black diamond is hilly and for the most part forest-covered. It is supposed that the carbonados have originated in the same

[86] Revista Industrial de Minas Geraes II, 5, 15 de Junho de 1895.

[87] Dr. Antonio Olyntho reports carbonados from Rio Abaeté in the State of Minas Geraes. Annaes da Escola de Minas, number 4, page 115. Rio de Janeiro, 1885.

way as the diamonds, but their origin is not altogether clear. It seems quite evident, however, that they are not genetically or directly related to volcanic rocks.

The geology of the black diamond region of Bahia is described by Branner, Crandall, and Derby. Other writers on carbonados are Baszanger, Damon, Descloiseux, Furniss, Gama, Gullana, Lawrence, Moissan, Rowe, and Stehr.

Other precious stones.—Brazil has produced many precious stones besides diamonds, notably rubies, garnets (Oliveira), emeralds, agates, topazes (Gorceix), phenacites (see Goldschmidt, Slavek, Smith). The phenacites are from Piracicaba, State of Minas. (See also Hussak and Fernandes.) These stones usually come from the regions of the Brazilian complex; the agates come chiefly from Rio Grande do Sul, where they have weathered from the "trapp" beds.

The Mining Laws of Brazil

GENERAL OBSERVATIONS

In Boubée's "Geologia Elementar," published in Rio de Janeiro in 1846, there is an appendix, without the name of the author, entitled "Indice da legislação Portuguese sobre as minas do Brasil," which brings the subject down ot the year 1816.

A chronologic list of the old mining laws of Brazil is given in "Livro das terras, ou collecção de leis, regulamentos e ordens," etcetera, etcetera, por I. M. P. de Vasconcellos, 4ª edição, Rio de Janeiro, 1885, pages 251-266, under the title "Legislação a respeito das minas. Indice chronologico das leis sobre minas do Brazil desde o seu descobrimento até 1817." (Extrahido do archivo da Torre do Tombo de Lisboa.)

When the Republic of Brazil was established the new constitution made the following provisions in regard to public lands:

> Article 64: "The mines and lapsed lands in their respective territories belong to the States, the Union being entitled only to the amount of territory that may be indispensable for the defense of the frontiers, fortifications, military constructions, and federal railways."
>
> Article 72, section 17: "The right of ownership is maintained in all its fullness, excepting disappropriation for public necessity or utility and after previous indemnity.
>
> "The mines belong to the owners of the soil, excepting the limitations that may be established by law for aiding the exploration of this branch of industry."

These provisions lead one to infer that legislation in regard to mining lands lies with the individual states. However, the National Congress

of Brazil passed a general mining law, and it was approved and put in force by the President January 6, 1915. It is decree number 2933. This law, translated into English, may be seen with the Bureau of Mines at Washington.

So far as I know, Bahia is the only state that has a code of mining laws. In other states legislation in regard to mineral lands is more or less indirect, obscure, and unsatisfactory.

The early history of mining in the State of Minas Geraes is given in Dr. Felicio dos Santos' Memorias do Districto Diamantino, chapter 28, pages 295-307, Rio de Janeiro, 1868. The mining laws of the State of Minas Geraes are listed in the Annaes da Escola de Minas, number 3, pages 239-250, Rio de Janeiro, 1884.

A brief history of mining in Brazil is given by Dr. Antonio Olyntho dos Santos Pires in his paper, "A Mineração; Riquezas Mineraes," published at Bello Horizonte in 1903, and in the "Livro do Centenario," volume III. It was also published in English in the "Brazilian Mining Review," at Rio de Janeiro, volumes II and III.

In his third volume, beginning at page 243, Dr. Calogeras gives a résumé of the legislation of the various states existing at the time his book on "As minas do Brasil e sua legislação" was published, in 1905. (See third title below.)

BIBLIOGRAPHIC REFERENCES TO MINING LAW

FRANCISCO IGNACIO FERREIRA: Repertorio Juridico do Mineiro. Consolidação alphabetico e chronologica de todas as disposições sobre minas. 356 paginas. Rio de Janeiro, 1884.

A. H. DE SOUZA BANDEIRA: A propriedade das minas. Estudo de direito administrativo. 8°, 75 paginas. Rio de Janeiro, 1885.

JOÃO PANDIÁ CALOGERAS: As minas do Brasil e sua legislação. 8°, volume I, 479 paginas. Rio de Janeiro, 1904. Volume II, 627 paginas, 1905; volume III, 243 paginas. Rio de Janeiro, 1905.

JOÃO PANDIÁ CALOGERAS: A lei de minas. (Parecer da Commissão Especial [da Camara dos Deputados].) 8°, 110 paginas. Rio de Janeiro, 1914.

STATE OF BAHIA: Regulamento geral de minas, para execução da lei no. 624 de 9 de Setembro de 1905. Bahia, 1907.

(THE FEDERAL MINING LAWS OF BRAZIL:) Decreto Legislativo no. 2933, de 6 de Janeiro de 1915. Regula a propriedade das minas. Ministerio da Agricultura, Industria e Commercio. 8°, 15 paginas. Rio de Janeiro, 1915.

WORKS OF TRAVEL IN BRAZIL

Those who work or travel in Brazil and those who wish to inform themselves about that country will naturally want to read books of travel thereon. The following are mostly old books, but they are among the

best. In reading them one must keep in mind that modern improvements have worked great changes in Brazil, just as they have in other countries. A valuable late work is "Brazil today and tomorrow," by L. E. Elliott, xi + 338 pages, New York, 1917. It is not a work of travel, but it gives much useful and trustworthy information about the country at the present time.

Professor and Mrs. Louis Agassiz: A journey in Brazil. xix + 450 pages, illustrated. Boston, 1868. This work was published in French at Paris, 1869.

Henry Walter Bates: The naturalist on the River Amazon. Several editions, illustrated. London, 1863 to 1892. A delightful book describing the author's life in the upper Amazon Valley.

Thomas P. Bigg-Wither: Pioneering in south Brazil. Two volumes, illustrated. London, 1878. The author was a civil engineer; his book tells of his life in the interior of Paraná.

Richard F. Burton: Explorations of the highlands of Brazil. Two volumes, illustrated. London, 1869. The book describes a trip through Minas Geraes and down Rio São Francisco to the ocean.

George Gardner: Travels in the interior of Brazil . . . during the years 1836-1841. 8°, xvi + 562 pages. London, 1846 and 1849. The author was an English botanist; most of his travels were in Ceará, Piauhy, Bahia, and Minas Geraes.

Daniel Kidder: Sketches of residence and travel in Brazil. Two volumes. illustrated. Philadelphia, 1845. Dr. Kidder was a Protestant missionary. He traveled over nearly all of Brazil and wrote simply and clearly.

Henry Koster: Travels in Brazil. Second edition, two volumes. London, 1817. It has been published also in French and German. The author traveled in Pernambuco, Parahyba, Rio Grande do Norte, and Ceará.

Algot Lange: The lower Amazon. 8°, illustrated, 460 pages. New York, 1914. Observations in regard to the conditions of life in the region about Pará.

John Mawe: Travels in the interior of Brazil, particularly in the gold and diamond districts of that country. 8°, illustrated. Philadelphia, 1816. There are other editions besides those in French, Italian, Dutch, and German. This is the first authentic account of the mining regions of Brazil.

Auguste de Saint-Hilaire: This author was a distinguished French botanist who wrote a series of volumes giving detailed accounts of his travels in different parts of Brazil. He was a keen observer and a faithful, trustworthy writer. His travels are given here in the order of their publication:

1. Voyage dans les provinces de Rio de Janeiro et de Minas Geraes. Two volumes. Paris, 1830.
2. Voyage dans le district des diamans et sur le littoral du Brésil. Two volumes. Paris, 1833.
3. Voyage aux sources du Rio de São Francisco et dans le province de Goyaz. Two volumes. Paris, 1848.
4. Voyage dans l'interieur du Brésil. Two volumes. Paris, 1850.
5. Voyage dans les provinces de Saint Paul e de Sainte Cathérine. Two volumes. Paris, 1851.

Herbert H. Smith: Brazil, the Amazons and the coast. 8°, illustrated, 644 pages. New York, 1879.

Richard Spruce: Notes of a botanist on the Amazon and Andes, edited by A. R. Wallace. Two volumes, illustrated. London, 1908.

James W. Wells: Exploring and traveling three thousand miles through Brazil from Rio de Janeiro to Maranhão. Two volumes, 8°, illustrated. London, 1886. The author was a civil engineer; the book is interesting and trustworthy, but it contains a great many absurd errors in Portuguese.

Climatic Conditions

Inasmuch as Brazil lies mostly within the tropics, it is important that the climatic conditions be kept in mind, both in connection with field-work in geology and with the carrying on of mining and other operations directly related to geology.

Some parts of Brazil have as fine climate as can be found anywhere in the world; such are the highlands of Minas Geraes and Goyaz and the southern states—São Paulo, Paraná, Santa Catharina, and Rio Grande do Sul. The high, dry parts of the interior are usually healthful, but the swampy, forest-covered portions of Amazonas, Pará, and Matto Grosso should be avoided unless one is proof against malarial and intestinal diseases.

Of the practical difficulties of dealing with malarial and other tropical diseases in the Amazon forest regions one can get an idea by reading "Recollections of an ill-fated expedition to the headwaters of the Madeira River in Brazil," by Neville B. Craig, Philadelphia, 1907. No one should delude himself by supposing that the sanitary measures that have been so successfully carried out on the Panama Canal Zone and in the city of Rio de Janeiro are practicable in a region like that of the Amazon Valley.

Good works on the climate of Brazil are:

F. M. Draenert: O clima do Brasil. Rio de Janeiro, 1890.

L. Cruls: Le climat de Rio de Janeiro (also in Portuguese). Rio de Janeiro, 1892.

L. Cruls: Le climat du Brésil, Paris, 1896.

C. M. Delgado de Carvalho: Météorologie du Brésil. 8°, illustrated. London, 1917. This last has a bibliography at pages 518-525.

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BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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GEOLOGY AND STRATIGRAPHY OF THE AREA OF PALEOZOIC ROCKS IN THE VICINITY OF HUDSON AND JAMES BAYS[1]

BY T. E. SAVAGE AND FRANCIS M. VAN TUYL

(*Presented before the Society December 29, 1916*)

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[1] Manuscript received by the Secretary of the Society October 24, 1918

Introduction

The explorations of several geologists have contributed to our knowledge of the Paleozoic rocks of the Hudson Bay region, among whom the names of Bell, Tyrrell, McInness, and Parks will always be associated in an important way with the geology of this region. These men have shown that Ordovician, Silurian, and Devonian strata are represented in the great sedimentary outlier lying west and south of Hudson and James bays. However, the succession and detailed sections of the formations had not been made out, and it had not been determined in all cases what horizons of these systems were present in the region, nor was it certain that all of the formations there present had been recognized.

From the standpoint of paleogeography and historical geology, it is highly desirable that the definite and complete sequence of the Paleozoic formations and their faunas in this region should be determined, as from these could be established what northern sea connections existed during the deposition of corresponding deposits in other parts of the continent. Such a systematic study of the stratigraphy of this region was recently made possible by a grant from the Graduate School of the University of Illinois, and an expedition to the region was made by the writers during the summer of 1916.

It was known in general that the Ordovician strata were present farthest north in this region, and that younger Silurian and Devonian beds bordered the bay successively farther south. The distribution of the rocks of the various systems suggested that the strata dipped toward the bay at a rate somewhat greater than the fall of the streams, and that along the rivers the older rocks were exposed farthest west and successively younger strata would be encountered farther east toward the bay. It was thought that by making as detailed sections and as full collections of fossils as possible across the belt of each system on at least two or three rivers, and combining these sections, a rather complete succession of the rocks present would be obtained. On account of the low, swampy character of the interstream areas and the thick accumulations of peat and moss that generally cover the surface, the rock exposures are practically confined to the banks of the larger streams which, almost without exception, flow across the belt

of sedimentary strata. Hence the plan of work was to follow up a river with canoes, portage across the divide into the adjacent river basin, follow that down to the bay, proceed along the coast of the bay to the next important river, ascend this, cross the divide, and follow down the next, etcetera. In this manner the sequence and detailed sections of the strata and a careful collection of their fossils were made of the Ordovician rocks exposed along Nelson and Shammattawa rivers; of the Silurian strata along the Severn, Winisk, and Ekwan rivers, and of the Devonian beds at the south end of the bay, along the Moose and its tributary, the Abitibi River.

The general succession and classification of the Paleozoic rocks recognized in the Hudson Bay region is shown in the following table:

Classification of Paleozoic Rocks of Hudson and James Bay Region

	Thickness in feet
Devonian system	
Upper Devonian	
Long Rapids shale	
Correlated with the Sweetland Creek shale of Illinois and Iowa and with the corresponding shale horizon in other parts of North America	55
Abitibi River limestone	
Correlated with the lower strata of the Upper Devonian in Iowa and northwest Illinois; upper rocks of Devonian age in the Lake Winnipeg region and farther west and northwest in North America . . . About	110
Middle Devonian?	
Sextant sandstone and shale	
Contains no fossils; presumably Middle Devonian, but in the absence of fossils no correlation has been attempted	75
Silurian system	
Niagaran series	
Attawapiskat coral reef	
Correlated in time with the late Niagaran rocks containing numerous corals in Ontario and the upper Mississippi Valley . . . About	85
Ekwan River limestone	
Correlated with the rocks of early to middle Niagaran age in Ontario, and about equivalent in time to the lower and middle parts of the Niagaran of the upper Mississippi Valley . . . About	100
Alexandrian series	
Severn River limestone	
Correlated with the lower part of the Silurian rocks in the Lake Timiskaming region, the lower part (Hendricks dolomite and Fiborn limestone) of the Silurian	

	Thickness in feet
of northern Michigan, and the upper part of the Silurian rocks west of Lake Winnipeg; with the Cataract formation of Ontario, and the Sexton Creek and Brassfield limestones of the Mississippi Valley.............	75
Port Nelson limestone	
Correlated with the basal part of the Stonewall limestone of western Manitoba, especially the lower part of the Silurian exposed in the vicinity of Grand Rapids of Saskatchewan River; with the upper part of the Mayville limestone of Wisconsin, and with the lower part of the Silurian limestone in Alaska, Utah, and western North America ....About	35
Ordovician system	
Cincinnatian series	
Shammattawa limestone	
Correlated with the Upper Ordovician (Stony Mountain) limestone in the vicinity of Lake Winnipeg; the Fish Haven dolomite of Utah; the Bighorn dolomite of Wyoming, and the upper and middle parts of the Fremont limestone of Colorado. Equivalent in time to some part of the Richmond and Maquoketa of the Ohio and Mississippi valleys..............................	75 to 80
Mohawkian series	
Nelson River limestone	
Correlated with the lower Ordovician rocks of the Lake Timiskaming region; the Winnipeg limestone in the vicinity of Lake Winnipeg. About equivalent in time to the Galena limestone of the upper Mississippi Valley and the Trenton limestone of New York and eastern Canada ....About	70

Ordovician Rocks in the Hudson Bay Region

LOCATION

The main body of Ordovician strata in the Hudson Bay region occurs in the northern part of the sedimentary area where they outcrop in a broad, roughly crescentic belt that is bounded on the west by pre-Cambrian crystallines and on the east by the Silurian strata which lap on them or in places transgress them in a westward direction.

EARLIER STUDIES

Ordovician rocks on the Nelson and Churchill rivers were briefly described by Bell[2] in 1879. On the basis of the very few fossils collected

[2] Robert Bell: Report on explorations on the Churchill and Nelson rivers and around God's and Island lakes. Geol. Survey of Canada, Summary Rept., 1878-1879, pp. 1-72C.

by Bell, Whiteaves referred these rocks to the Trenton limestone and considered them the equivalents of the Galena limestone of Wisconsin and Illinois. The Ordovician limestones outcropping on Churchill River overlie a massive, dark gray quartzite which outcrops at the mouth of this river and which Bell compared with the gold-bearing lower Cambrian quartzites of Nova Scotia, while along the Nelson River these limestones rest on what are thought to be pre-Cambrian crystallines.

The geology of the Nelson and Churchill rivers has been more recently treated by McInness,[3] who summarized the results of Bell's work and discussed additional data gathered by himself. His studies of the sedimentary rocks were meager, and little new of importance was added.

In the report of the Hudson Bay exploring expedition of 1912 by J. B. Tyrrell,[4] the Ordovician rocks on the Shammattawa, a branch of Hayes River, were described and a list of fossils identified by Parks was given, on the evidence of which the rocks were considered about the age of the top of the Trenton of eastern Canada.

The presence of Ordovician rocks much farther south was shown by Whiteaves from a study of fossils collected by Wilson[5] on the Drowning and Little Current rivers, two tributaries of the Kenogami, a branch of the Albany River west of James Bay.

From fossils collected near the head of Frobisher Bay, Schuchert[6] has demonstrated the presence of corresponding Ordovician strata as far north as Baffin Land.

PRESENT STUDIES

The present studies of the Ordovician rocks in the Hudson Bay region were confined to outcrops along Nelson and Shammattawa rivers and a few of their tributaries.

Outcrops of Ordovician limestone and dolomite occur at intervals in the banks of Nelson River for a distance of about 22 miles. The oldest strata are exposed farthest west—about 95 miles above the mouth of the river and only a short distance east of an outcrop of crystalline rock—but the contact of the limestone with the crystallines was not seen at this place. These limestones include strata corresponding in age to the latter part of the Mohawkian epoch, about the time of the Galena dolomite, and

[3] William McInness: The basins of Nelson and Churchill rivers. Canada Dept. of Mines, Mem. no. 30, 1913, pp. 1-142.

[4] J. B. Tyrrell: Hudson Bay exploring expedition. 22d Rept. Ontario Bureau of Mines, 1913, pp. 188-239.

[5] W. J. Wilson: Geological reconnaissance of a portion of Algoma and Thunder Bay districts, Ontario. Canada Geol. Survey, 1909, pp. 49 and *ff*.

[6] Charles Schuchert: Proc. U. S. Nat. Mus., vol. xxii, 1909, pp. 143-177.

to the latter part of the Cincinnatian epoch, about the age of the Richmond or Maquoketa of the upper Mississippi Valley.

The Ordovician rocks in this region that belong to the Mohawkian series are here designated the Nelson River limestone, from Nelson River, in the banks of which they are well exposed. The strata considered equivalent to some part of the Richmond of the United States will be referred to as the Shammattawa limestone, from the river of that name along the banks of which the best exposures were found.

As elsewhere in this region, the strata exposed along Nelson River have a general dip toward the east, or downstream, a little steeper than the gradient of the stream. Gentle undulations in the strata are also common and low arches 10 or 50 or more feet high are not rare.

ORDOVICIAN DEPOSITS EXPOSED ON NELSON RIVER

Nelson River limestone.—The lowest layers of Nelson River limestone consist of sandy, bluish gray dolomite, and contain *Receptaculites oweni* and other fossils similar to those occurring at a somewhat higher level in the limestones exposed at the Upper Limestone Rapids, about 10 miles farther down the river.

At the Upper Limestone Rapids, which are about one mile long, there is exposed a thickness of nearly 25 feet of gray limestone mottled with brownish dolomite, in layers 6 to 30 inches thick. These contain such characteristic fossils as *Receptaculites oweni*, *Hormotoma winnipegensis*, *Maclurina manitobensis*, associated in the same layers with numerous corals belonging to the genera Halysites, Favosites, and Columnaria, and cephalopods belonging to the genera Orthoceras, Cyrtoceras, and Poterioceras.

For a distance of 4 or 5 miles above these rapids a low ledge of gray limestone, mottled with patches of yellowish brown dolomite 3 to 16 feet high, outcrops in the north bank of the river at frequent intervals. The layers, which lie nearly horizontal, are 3 or 4 to 12 inches thick and furnished fossils similar to those above mentioned.

Between one and two miles below the Upper Limestone Rapids a ledge of gray, non-dolomitized limestone outcrops in the south bank to a height of 6 to 10 feet. These strata dip gently toward the east, so that successively higher layers appear at the top in an eastward direction. This limestone, which aggregates 15 or more feet in thickness, weathers into thin, irregular layers which in appearance very closely resemble weathered faces of exposures of undolomitized Galena limestone in Fayette County and at a few other places in northeastern Iowa.

The fossils from this ledge include *Receptaculites oweni* and the greater

number of the species of gastropods and corals that were found in the exposures of dolomite farther up the river. These outcrops were within such short distances of one another and the eastward dip of the rocks is so gentle that it is believed they afford a practically complete section of the Nelson River limestone in this region.

Shammattawa limestone along Nelson River.—The Shammattawa limestone is thought to represent Maquoketa or Richmond time. Rocks of this age have not been definitely recognized by previous workers in the region. The lowest beds of the Shammattawa limestone are exposed about 2½ miles above the Lower Limestone Rapids on Nelson River, about 3 miles below the last appearance of the Nelson River limestone, but the contact of the Nelson River and Shammattawa limestones was not found. At the head of the Lower Limestone Rapids a corresponding level of the Shammattawa limestone is exposed, showing a thickness of 7 to 9 feet of gray, thin-bedded limestone overlain by 3 to 5 feet of brown, fine-grained, thin-bedded dolomite. The surfaces of the layers of the dolomite were covered with brachiopod shells and impressions, the more common being *Strophomena* cf. *fluctuosa, Strophomena* sp. *Rafinesquina* cf. *alternata,* and *Rhynchotrema* aff. *capax.* In the south bluff of the river bordering the Lower Limestone Rapids a ledge of gray, fine-grained limestone, in thick and thin layers, is exposed to a height of about 28 feet. This limestone overlies the dolomite horizon last mentioned and contains *Rhynchotrema* near *capax, Dinorthis* aff. *subquadrata,* and other fossils characteristic of the Richmond strata in the United States.

About 8 miles below the Lower Limestone Rapids a still higher level of the Shammattawa limestone is exposed in a low arch in the south bank of Nelson River to a maximum height of 6 or 7 feet. These strata consist of yellowish gray, rather thin-bedded limestone which contains fragments of *Isotelus* and other species of fossils characteristic of the deposits of Richmond time.

Port Nelson limestone along Nelson River.—The Port Nelson limestone is the oldest Silurian formation known in the Hudson Bay region. It consists of yellowish brown, rather fine-grained dolomite, certain layers of which contain casts and molds of shells of *Virgiana decussata* in great numbers. The thickness is probably somewhat more than 30 feet. As far as known, this limestone outcrops nearer to Port Nelson, at the mouth of Nelson River, than any other formation of Paleozoic age; hence it is designated the Port Nelson limestone.

The succession and the stratigraphic and faunal relations of the Paleozoic rocks exposed along Nelson River are shown in the detailed section and fossil lists given below. The species marked sp. in the fossil lists on

the following pages are mostly new. They will be figured and described in a paper now in preparation.

Detailed Section of Paleozoic Strata exposed along Nelson River

	Thickness in feet
Silurian system	
Alexandrian series—about 28 feet	
Port Nelson limestone	
8. Dolomite, brown, in regular layers 4 to 10 inches thick, with few fossils; exposed about 4 miles below the Lower Limestone Rapids. The fossils listed below are from masses of this dolomite along the bank of the river some distance below the outcrop:	28
Zaphrentis sp.	
Favosites sp.	
Dinobolus sp.	
Stropheodonta sp.	
Virgiana decussata.	
Pterinea occidentalis.	
Hormotoma sp.	
Primitia mundula var. *incisa.*	
A gap in exposure	
Ordovician system	
Cincinnatian series	
Shammattawa limestone—about 47 feet	
7. Limestone, gray to yellowish brown, exposed in a low arch about 8 miles below the Lower Limestone Rapids; containing *Strophomena* sp., *Isotelus* sp., and a few other fossils.........................	7
A gap in exposure	
6. Limestone, gray, in layers 4 to 14 inches thick, exposed in an escarpment at the Lower Limestone Rapids, and containing the fossils:....................................	28
Streptelasma sp.	
Favosites near *favosus.*	
Strophomena cf. *fluctuosa.*	
Strophomena sp.	
Rhynchotrema near *capax.*	
Tetranota sp.	
5. Limestone, gray, passing above into one or more layers of yellowish brown dolomite: exposed one-half mile to one mile above the Lower Limestone Rapids, and containing the fossils:...	12 to 15
Streptelasma sp.	
Columnaria sp.	
Favosites near *favosus.*	
Plectambonites sericeus.	
Rafinesquina aff. *alternata.*	

Thickness in feet

Strophomena cf. *fluctuosa.*
Strophomena sp.
Rhynchotrema near *capax.*
Byssonychia cf. *tenuistriata.*
Tetranota sp.
Hormotoma cf. *gracilis.*
Maclurea aff. *cuneata.*
Trochonema sp.
Conularia sp.
Bumastus sp.

A gap in exposure

Mohawkian series

Nelson River limestone—about 68 feet

4. Limestone, gray, weathering into irregular layers 1 to 2 inches thick; exposed 1 to 2 miles below the Upper Limestone Rapids; containing the fossils listed below:...... 15

Receptaculites oweni.
Calapœcia aff. *canadensis.*
Halysites gracilis.
Halysites sp.
Hormotoma winnipegensis.
Maclurina sp.
Trochonema sp.
Cyrtoceras cf. *manitobense.*
Oncoceras (?) sp.

3. Dolomite and limestone, gray, mottled with brown fucoidal areas, in layers 12 to 30 inches thick; exposed at the Upper Limestone Rapids; containing the fossils:........ 25

Receptaculites oweni.
Streptelasma sp.
Calapœcia cf. *canadensis.*
Columnaria calacina.
Columnaria (*Paleophyllum*) *stokesi.*
Halysites gracilis.
Strophomena sp.
Dalmanella testudinaria var.
Hebertella aff. *bellarugosa.*
Hormotoma winnipegensis.
Maclurina cf. *manitobense.*
Maclurina sp.
Trochonema sp.
Endoceras cf. *proteiforme.*
Cyrtoceros cf. *manitobense.*
Poterioceros sp.
Bumastus sp.

2. Limestone and dolomite, gray, mottled, in rather thin layers; exposed about 2 miles above the Upper Limestone Rapids; containing the following fossils:......... 12

Receptaculites oweni.

Thickness in feet

Streptelasma sp.
Halysites gracilis.
Halysites sp.
Strophomena sp.
Hormotoma winnipegensis.
Maclurina cf. *manitobense.*
Maclurina sp.
Endoceras cf. *annulatum.*
Endoceras cf. *proteiforme.*
Cf. *Bumastus* sp.

A gap in exposure

1. Dolomite, gray to brown, sandy, grading below into a calcareous sandstone, in rather even layers; exposed about 10 miles above the Upper Limestone Rapids; containing the fossils: .... 14 to 18
Receptaculites oweni.
Hormotoma winnipegensis.
Maclurina sp.

CORRELATION OF NELSON RIVER LIMESTONE

The fauna and lithology of the Nelson River limestone exposed along Nelson River are remarkably similar to those of the rocks of late Trenton age in the Lake Winnipeg region. The more common species of fossils occurring in this limestone in the Nelson River region are listed below. The species in this list which have a cross in front of the name also occur in the Trenton limestone in the Lake Winnipeg region.

List of the more common Fossils from the Nelson River Limestone

+ *Receptaculites oweni.*
+ *Calapœcia* cf. *canadensis.*
+ *Columnaria calacina.*
+ *Columnaria (Paleophyllum) stokesi.*
+ *Halysites gracilis.*
+ *Dalmanella testudinaria* var.
+ *Hormotoma winnipegensis.*
+ *Maclurina manitobense.*
+ *Trochonema* cf. *umbilicatum.*
+ *Cyrtoceras manitobense.*
+ *Poterioceras* cf. *nobile.*

The species listed above are thought to indicate the Trenton (Galena of upper Mississippi Valley) age of the strata from which they came.

Williams[7] has described limestones of Middle Ordovician age in the

[7] M. Y. Williams: The Ordovician rocks of Lake Timiskaming. Geol. Survey of Canada, Mus. Bull. no. 17, Geological series, no. 27. June 7, 1915.

Lake Timiskaming region that so closely correspond in their lithology and fauna to those of the late Middle Ordovician in the localities above mentioned as to indicate that they also were laid down in the same province of deposition. Schuchert[8] has also reported a similar fauna from the Frobisher Bay region in Baffin Land.

It is thought that the late Middle Ordovician rocks in all of the above-mentioned localities were laid down in the same great epi-continental sea that advanced southward from the Arctic Ocean.

The Galena limestone of the upper Mississippi Valley is thought to be a nearly contemporaneous deposit with that of the Middle Ordovician limestones in the localities above mentioned and probably was deposited in an embayment of the same province. The Galena limestone lacks several of the coral species that are common in the deposits of Middle Ordovician age at the Hudson Bay and Lake Winnipeg localities. However, among the more common fossils of the Galena are *Receptaculites oweni* and species representing the genera *Hormotoma, Maclurina,* and *Trochonema* that are closely allied to species of these genera in the above list.

ORDOVICIAN ROCKS EXPOSED ON SHAMMATTAWA RIVER

No Paleozoic rocks are exposed in the banks of Hayes River below the mouth of the Shammattawa, but along the latter river outcrops of limestone are encountered about 28 miles above its mouth, above which they occur at intervals for a distance of about 15 miles. The rocks exposed along this river are all included in the Shammattawa limestone, and are considered to be about the age of the Maquoketa or Richmond strata of the Mississippi Valley.

About 60 miles farther southeast, on a branch of Echoing River, a tributary of the Shammattawa, limestones corresponding in age to the Nelson River limestone above described, and containing similar fossils, are exposed in low ledges at intervals for a distance of 5 to 8 miles.

A detailed section of the limestone outcropping in the banks of Shammattawa River and lists of fossils collected from the several members are given below:

SECTION OF ROCKS EXPOSED ALONG SHAMMATTAWA RIVER

Ordovician system
Cincinnatian series
Shammattawa limestone
2. Limestone, yellowish brown, porous; dolomitic above, mottled gray and brown below, forming the escarpment

[8] Charles Schuchert: Proc. U. S. Nat. Mus., vol. xxii, 1900, p. 149.

Thickness in feet

on the east side of the river at the rapids, and exposed in the upper part of the bluff 1 to 2 miles farther down the river; the fossils listed below occur in the lower part: 23

Zaphrentis sp.
Streptelasma latuscula var. *trilobata.*
Paleofavosites cf. *aspera.*
Paleofavosites sp.
Halysites sp.
Calapœcia cf. *canadensis.*
Strophomena cf. *lata.*
Strophomena tetrastriata.
Rafinesquina alternata.
Plectambonites sericeus.
Dinorthis cf. *subquadrata.*
Rhynchotrema near *capax.*
Trochonema cf. *umbilicatum.*
Trochonema sp.
Holopea media.
Hormotoma acuminata.
Hormotoma sp.
Actinoceras sp.
Cyrtoceras sp.
Cycloceras olorus var. *baffinense.*
Isotelus sp.
Bumastus sp.
Leperditia sp.

1. Limestone, gray, in rather thin layers, somewhat mottled with brown dolomitized areas; a zone of numerous gastropods (*Trochonema*, etcetera) present in the lower part; exposed in both banks of the river 2 or 3 miles below the rapids and also 4 miles above the rapids, where an arch of the strata brings this horizon above the level of the water; containing the fossils listed below: 15

Cerionites sp.
Zaphrentis sp.
Streptelasma latuscula var. *trilobata.*
Streptelasma sp.
Columnaria near *alveolata.*
Columnaria calicina.
Paleofavosites cf. *aspera.*
Paleofavosites sp.
Calapœcia canadensis.
Halysites catenulatus.
Halysites sp.
Dinobolus sp.
Schizocrania sp.

Rafinesquina cf. *alternata.*
Leptæna rhomboidalis.
Plectambonites sericeus.
Strophomena cf. *fluctuosa.*
Strophomena lævis.
Strophomena lata.
Strophomena nutans.
Strophomena tetrastriata.
Strophomena sp.
Dalmanella testudinaria var.
Dalmanella sp.
Dinorthis meedsi var. *arctica.*
Dinorthis cf. *subquadrata.*
Hebertella sp.
Rhynchotrema cf. *capax.*
Cf. *Glassia* sp.
Ctenodonta aff. *baffinensis.*
Vanuxemia cf. *baffinensis.*
Vanuxemia sp.
Cf. *Whitella sterlingensis.*
Clionychia cf. *excavata.*
Hormotoma acuminata.
Hormotoma cf. *gracile.*
Hormotoma sp.
Lophospira cf. *obtusa.*
Lophospira sp.
Bellerophon sp.
Straparollina sp.
Maclurea acuta
Maclurea sp.
Eccilimphalus sp.
Trochonema near *umbilicatum.*
Trochonema sp.
Holopea media
Oxydiscus sp.
Ascoceras cf. *boreale.*
Orthoceras sp.
Cycloceras cf. *olorus* var. *baffinensis.*
Cycloceras sp.
Discoceras shammattawense.
Cyrtoceras cf. *cornulum.*
Cyrtoceras sp.
Oncoceras tumidum.
Poterioceras tyrrelli.
Asaphus sp.
Bathyurus sp.
Illænas sp.
Encrinurus sp.
Ceraurus ? sp.

Pterygometopus sp.
Leperditia sp.

CORRELATION OF THE SHAMMATTAWA LIMESTONE

The fossils as well as the lithology of the Shammattawa limestone are remarkably similar to those of the Stony Mountain (Upper Ordovician) limestone in the Lake Winnipeg region and correspond also with those of the Bighorn dolomite in Wyoming and those of the Montoya limestone of New Mexico. The rocks at all of these localities consist of gray to yellowish, subscrystalline limestone, with layers and mottled areas of yellowish brown dolomite. The more common species of fossils occurring in the Shammattawa limestone are shown in the following list of species. In this list the species having a cross after the name are reported from the Stony Mountain limestone of the Lake Winnipeg region, and those having a cross in front of the name occur also in the Bighorn dolomite of Wyoming.

List of the more common Fossils from the Shammattawa Limestone

Streptelasma latuscula.+
+ *Streptelasma latuscula* var. *trilobata*.+
+ *Streptelmasma* sp.
+ *Columnaria alveolata*.+
+ *Columnaria* (*Paleophyllum*) *stokesi*.+
+ *Calapœcia canadensis*.+
+ *Paleofavosites asper*.+
+ *Halysites gracilis*.+
Hallopora sp.
Ptilodictya sp.+
Dinobolus sp.+
Rafinesquina cf. *alternata*.+
+ *Strophomena fluctuosa*.+
Strophomena sp.
+ *Dinorthis aff. subquadrata* + (with coarse striæ).
Platystrophia near *crassa*.
+ *Rhynchotrema* aff. *capax*.+
+ *Holopea* cf. *excelsa*.
Maclurina sp.
+ *Trochonama* cf. *umbilicatum*.+
Hormotoma sp.
Raphistoma sp.
Ascoceras sp.
Cyrtoceras sp.
Bumastus sp.

The fossils in the foregoing list indicate the Richmond age of the strata from which they came. The close similarity of this fauna in such widely

separated localities as the Wyoming, Lake Winnipeg, and Hudson Bay regions may be seen from the foregoing table. This resemblance extends not only to the specific identity of the more common fossils, but also to the unusual coral associates in this fauna and the peculiar coral elements, as *Streptelasma latuscula* var. *trilobata* and an undescribed species of *Streptelasma* having the convex side flattened. It also includes similar variations in such characteristic brachiopod species as *Dinorthis* near *subquadrata* having unusually coarse radiating striæ, and a large, coarse form of *Rhynchotrema* cf. *capax.* A similar fauna was also found by Walcott in the upper part of the Fremont limestone of Colorado. The similarity in the faunas of this age in the different localities is such as to indicate that the Richmond strata in the Colorado, Wyoming, Lake Winnipeg, and Hudson Bay regions were deposited in the same marine province or basin of deposition, which was doubtless connected at the north with the Arctic Ocean. This fauna is quite different from the more or less contemporaneous fauna of the Maquoketa in the upper Mississippi Valley, or from that of the Richmond farther east, in Indiana and Ohio.

When the meager bryozoa fauna associated with *Dinorthis* aff. *subquadrata* and *Rhynchotrema* near *capax* and other late Cincinnatian fossils in the Hudson Bay and Lake Winnipeg regions is compared with the great number and variety of species belonging to this class of fossils in the Maquoketa and Richmond strata of the Mississippi and Ohio valleys, many of the bryozoa in the latter region belonging to families not represented in the late Cincinnatian fauna of the Hudson Bay region, it seems impossible that the source of the Maquoketa and Richmond faunas of the eastern and central United States could have been in the north, as has generally been assumed. It is much more probable that the fauna of the Maquoketa and Richmond of the Mississippi and Ohio valleys were of southern or eastern origin, and that they invaded the interior of North America from the south, as shown on the paleogeographic map, figure 1. On this map, as on those that follow, the lined areas represent the extension of the seas on the continent.

Silurian Rocks in the Hudson Bay Region

EARLIER STUDIES

Exposures of Silurian rocks along Attawapiskat River were mentioned by Bell[9] in 1886, who described the Silurian coral reefs outcropping for 33 miles above the head of Lowasky Island.

[9] Robert Bell: Report on an exploration of portions of the Attawapiscat and Albany rivers. Geol. Survey of Canada, Summary Rept., 1886, pp. 24G-29G.

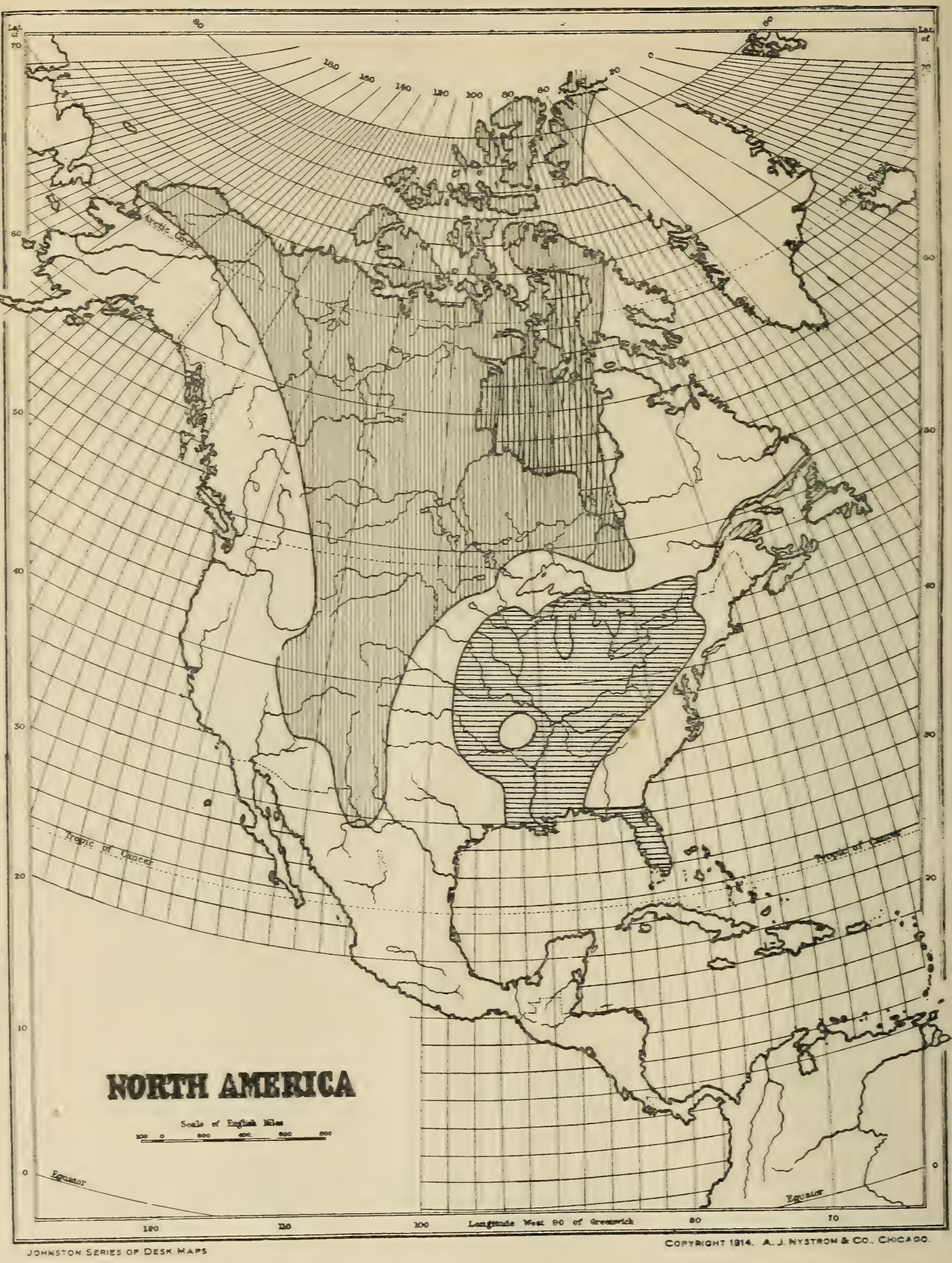

FIGURE 1.—*Generalized Map of North America during Deposition of Shammattawa and Stony Mountain Limestone*

Richmond time. Lined areas represent seas.

In a report on his exploration of the country from Lake Winnipeg to Hudson Bay, Low[10] described limestones or dolomites having a total thickness of not more than 100 feet, the fossils of which he regarded as not older than the Galena and possibly as young as the Niagara. Dowling[11] noted horizontal limestones along Ekwan River, between 33 and 100 miles above its mouth. He recognized the coral reef mentioned by Bell along Attawapiscat River. He collected a few fossils which were identified by Whiteaves, who thought the horizon they represented was rather high in the Silurian.

In the report on the Algoma and Thunder Bay districts, Ontario, there is given a list of fossils collected by W. J. Wilson[12] from the Nagagami and other branches of the Kenogami River, and identified by Whiteaves, who thought they indicated the Silurian age of the rocks from which they came.

In 1910 McInnes[13] described the structure and character of the rocks exposed on Winisk River. The Silurian age of these strata was determined by Whiteaves on the basis of seven species of fossils that he was able to identify of those collected by McInnes from that region.

Tyrrell[14] described limestones exposed along the Severn and Fawn rivers and gave a list of fossils from them, which were identified by Parks, on the basis of which their age was considered approximately that of the Guelph of eastern Canada.

PRESENT STUDIES

The oldest Silurian rocks in the region outcrop about 4 miles below the Lower Limestone Rapids on Nelson River, described in the section of rocks exposed along that river under the name of Port Nelson limestone. At this place a thickness of 28 feet of rather even-bedded, yellowish dolomite is present above the level of the water. Only a few fossils were found in the exposed part of this ledge, but farther down the river numerous fresh fragments of fine-grained, yellow dolomite crowded with shells of *Virgiana decussata* and other fossils indicate that this zone of the Silurian is present along the river, probably at a little lower horizon than

[10] A. P. Low: Preliminary report on an exploration of the country between Lake Winnipeg and Hudson Bay. Geol. Survey of Canada, Summary Rept., 1886, p. 18F.

[11] D. B. Dowling: Report on an exploration of Ekwan River, Sutton Mill lakes, and part of the west coast of James Bay. Geol. Survey of Canada, Summary Rept., 1901, pp. 1-60F.

[12] W. J. Wilson: Report on a portion of Algoma and Thunder Bay districts. Geol. Survey of Canada, 1909, pp. 34-41.

[13] W. McInnes: Report on a part of the Northwest Territories drained by the Winisk and Attawapiscat rivers. Geol. Survey of Canada, 1910, pp. 1-54.

[14] J. B. Tyrrell: Report on the Hudson Bay exploring expedition. 22d Ann. Rept. Ontario Bureau of Mines, 1912, pt. 1, pp. 161-209.

that in the exposure above described. *Virgiana decussata* marks a definite zone near the base of the Silurian section (Stonewall limestone) in the vicinity of Grand Rapids, on the lower Saskatchewan River, and it doubtless marks a corresponding horizon of Silurian on Nelson River.

Farther south, along the west side of Hudson and James bays, Silurian limestones are well exposed in the banks of the Severn, Winisk, Ekwan, and Attawapiskat rivers. One of the most complete sections of the Silurian in the entire region outcrops along Severn River between 40 and 25 miles above its mouth. The succession of strata exposed along this stream and their faunas are shown in the following detailed section:

DETAILED SECTION OF STRATA EXPOSED ALONG SEVERN RIVER

Silurian system

Niagaran series

Attawapiskat coral reef — Thickness in feet

10. Limestone consisting of separate ridges or domes of structureless limestone composed of stromatoporoid masses, corals, and other fossils, ranging from a few to 100 or more feet in diameter and up to 30 or more feet high, with thinly and evenly bedded, fine-grained limestone layers lapping up on the flanks of the domes and ridges, from which they dip away at angles of 20 to 30 degrees, but become nearly horizontal at a distance from them; exposed at Limestone Island and at Long Portage, about 10 miles farther down the river; containing the fossils listed below: .... 75 to 85

Zaphrentis patens.
Zaphrentis stokesi.
Strombodes sp.
Pycnostylus elegans.
Paleofavosites aspera.
Favosites favosus.
Favosites cf. *forbesi.*
Favosites hisingeri.
Favosites sp.
Lyellia affinis.
Heliolites sp.
Fenestella subarctica.
Stropheodonta sp.
Stropheodonta philomela.
Orthis aff. *flabellites.*
Pentamerus sp.
Gypidula sp.
Camarotœchia sp.
Atrypa cf. *reticularis.*
Glassia variabilis.

	Thickness in feet
Spirifer aff. *crispus*.	
Spirifer sp.	
Reticularia septentrionalis.	
Conocardium sp.	
Liospira stevensoni.	
Gyronema speciosa.	
Diaphorostoma perforata.	
Cœlidium sp.	
Orthoceras sp.	
Huronia sp.	
Actinoceras cf. *clowei*.	
Cycloceras sp.	
Phragmoceras sp.	
Bronteus ekwanensis.	
Encrinurus sp.	
Leperditia hisingeri var.	
A short gap in exposure	
Ekwan River limestone	
9. Limestone, yellowish gray, non-dolomitic, in thin, regular layers, containing *Trimerella* sp. and other fossils listed below; exposed in an arch in the north bank of the river 1 to 2 miles above Limestone Island: ....About	40
Streptelasma sp.	
Favosites favosus.	
Favosites sp.	
Halysites catenulatus.	
Trimerella ekwanensis.	
Pentamerus sp.	
Gypidula sp.	
Atrypa cf. *reticularis*.	
Spirifer sp.	
Hormotoma whiteavesi.	
Hormotoma sp.	
Gyronema cf. *dowlingi*.	
A short gap in exposure	
8. Limestone, gray, fine grained, thin bedded, with nodules and bands of chert in some places; containing stromatoporoids and other fossils listed below; exposed at the first rapids below the mouth of Fawn River:	15
Actinostroma sp.	
Paleofavosites aspera.	
Favosites favosus.	
Alveolites sp.	
Halysites catenulatus.	
Trimerella ekwanensis.	
Stropheodonta cf. *philomela*.	

Thickness in feet

Orthis cf. *flabellites.*
Dalmanella cf. *elegantula.*
Pentamenus sp.
Camarotœchia sp.
Glassia variabilis.
Atrypa cf. *reticularis.*
Spirifer aff. *crispus.*
Rhynchospira lowi.
Liospira sp.
Hormotoma whiteavesi.
Euomphalopterus tyrrelli.
Strophostylus filicinctus
Kionoceras cancellatum
Encrinurus sp.
Calymene sp.

7. Limestone, gray, dense, fine grained, thin bedded, with concretions and bands of chert in some places, and an 8-foot ledge of dolomite in the lower part; exposed a short distance above the first rapids below the mouth of Fawn River; containing the fossils listed below: 20

Stromatoporoids.
Streptelasma pygmæum var. *occidentale.*
Streptelasma sp.
Amplexus severnensis.
Aphyllostylus gracilis.
Paleofavosites aspera.
Favosites favosus.
Favosites hisingeri.
Favosites sp.
Alveolites niagarensis.
Calopœcia cf. *canadensis.*
Aulopora sp.
Syringopora bifurcata.
Halysites catenulatus.
Lyellia sp.
Pachydictya sp.
Trimerella ekwanensis.
Leptœna parvula.
Leptœna sp.
Stropheodonta cf. *leda.*
Stropheodonta philomela
Stropheodonta sp.
Orthis flabellites.
Dalmanella sp.
Glassia variabilis.
Eotomaria sp.
Hormotoma whiteavesi.

Thickness in feet

Lophospira sp.
Bellerophon sp.
Euomphalus minor.
Euomphalus rotundus.
Euomphalopterus cf. *tyrrelli.*
Euomphalopterus sp.
Trochonema sp.
Phanerotrema sp.
Pycnomphalus sp.
Orthoceras sp.
Actinoceras hearsti.
Actinoceras sp.
Trochoceras sp.
Barrandeoceras sp.
Phragmoceras whitneyi.
Illænus sp.
Bronteus sp.
Encrinurus sp.
Leperditia hisingeri var.

6. Limestone, mostly non-dolomitized, in rather regular layers, brachiopods common in the lower part and corals and stromatoporoids more abundant in the upper; exposed in an arch near the mouth of Fawn River 25

Streptelasma pygmæum var. *occidentale.*
Favosites hisingeri.
Halysites catenulatus.
Stropheodonta sp.
Liospira sp.
Stroparollus sp.
Diaphorostoma perforata.
Encrinurus cf. *lævis.*

A gap in exposure
Alexandrian series
Severn River limestone

5. Limestone, gray, fine grained, in rather even layers, with numerous shells of *Leperditia* and other ostracods in a zone near the top; exposed about one mile above the mouth of Fawn River.................... 35

Clathrodictyon sp.
Favosites favosus.
Favosites hisingeri.
Stropheodonta acanthoptera.
Leptæna parvula.
Orthis flabellites.
Camarotœchia ? winiskensis.
Cf. *Whitfieldella julia.*
Ctenodonta subovata.

	Thickness in feet
Pterinea occidentalis.	
Cypricardinia sp.	
Hormotoma whiteavesi.	
Hormotoma sp.	
Cf. *Stroparollus* sp.	
Orthoceras sp.	
Leperditia hisingeri var.	
Leperditia hisingeri var. *fabulina.*	
Isochilina grandis var. *latimarginata.*	
4. Limestone, gray, thin bedded; exposed about one mile below the first limestone rapids encountered on descending the river..............................	4
3. Dolomite, brown, structureless, vesicular, without fossils; exposed in the bluff at the foot of the upper, or first, limestone rapids encountered on descending the river	8
2. Ledge of gray, dense, irregularly bedded, undulating and domed limestone, in layers 2 to 5 feet thick, composed largely of stromatoporoid masses from a few inches to a few feet in diameter, alternating with zones of fine-grained, thin-bedded limestone 2½ to 3½ feet thick; exposed at the upper limestone rapids	20
Streptelasma pygmæum var. *occidentale.*	
Favosites sp.	
Stropheodonta acanthoptera.	
Stropheodonta sp.	
Schuchertella sp.	
Orthis flabellites.	
Cf. *Whitfieldella julia.*	
Hormotoma whiteavesi.	
Encrinurus sp.	
Leperditia hisingeri var.	
Isochilina sp.	
1. Limestone and dolomite, brown, fine grained, imperfectly bedded, with few fossils, showing one or two bands of stromatoporoid structure; exposed on the west side of a small island one-half mile above the upper, or first, limestone rapids encountered on descending the river..............................	8

WINISK RIVER SECTION

Limestones of Silurian age outcrop along the banks of the Winisk River in several places between 15 and 40 miles above its mouth. An important anticlinal fold extending in a direction a little north of west crosses the Winisk River valley 4 or 5 miles above the mouth of its tributary, the Shammattawa. At this place the base of the Silurian is seen to rest unconformably on quartzites of pre-Cambrian age, the Ordovician

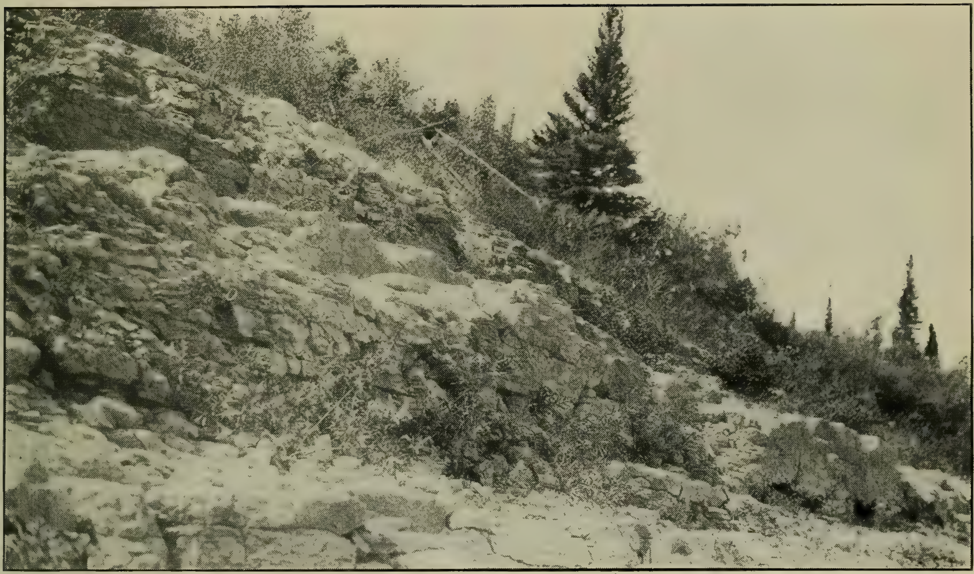

FIGURE 1.—BASAL PORTION OF THE SEVERN RIVER LIMESTONE; EXPOSED ALONG SEVERN RIVER

FIGURE 2.—SEVERN RIVER LIMESTONE; EXPOSED ALONG SHAMMATTAWA RIVER ABOUT 6 MILES ABOVE ITS JUNCTION WITH THE WINISK.

EARLY SILURIAN LIMESTONES IN THE HUDSON BAY REGION

strata which probably were originally present having been removed during the post-Ordovician erosion interval before the Silurian rocks were deposited. This fold resulted in such an elevation of the rocks of the region farther west that the sedimentary rocks have been eroded from the larger part of the area. In the banks of the Winisk River limestones are exposed at intervals for a distance of about 16 miles above this fold and for 6 or 8 miles below it. Ledges of limestone 15 to 25 feet high in many places border one or both sides of the Shammattawa River for a distance of 10 or 12 miles above its junction with the Winisk.

All the limestones exposed in the Winisk River basin are of Silurian age, and the greater part of them correspond to the Severn River limestone, as that formation is developed along Severn River. The Ekwan limestone and the Attawapiskat coral reef, the youngest and most conspicuous Silurian formation present along the Severn and Ekwan rivers, are not exposed in the banks of the Winisk, the outcrop being pushed eastward and northward by the elevation of the arch above mentioned. The coral reef horizon outcrops in a few places farther north along the shore of Hudson Bay near Wabuk Point and in places for several miles farther north.

A detailed section of the Silurian rocks outcropping along Winisk River and its tributary, the Shammattawa, is given below.

SECTION OF ROCKS EXPOSED ALONG WINISK AND SHAMMATTAWA RIVERS

	Thickness in feet
Silurian system	
Alexandrian series	
Severn River limestone	
3. Limestone, rather fine grained, gray, with occasional layers of buff, dolomitic limestone containing few fossils; exposed in the banks of Winisk River below the mouth of the Shammattawa and in the upper part of the bluffs bordering the Shammattawa; containing the fossils named below:	25
Streptelasma pygmæum var. *occidentale.*	
Zaphrentis stokesi ?	
Favosites favosus.	
Cf. *Alveolites niagarensis.*	
Trimerella ekwanensis.	
Stropheodonta acanthoptera.	
Stropheodonta cf. *philomela.*	
Schuchertella sp.	
Dalmanella elegantula.	
Camarotœchia ekwanensis.	
Camarotœchia ? winiskensis.	
Atrypa cf. *reticularis.*	
Rhynchospira lowi.	

Thickness in feet

Hormotoma whiteavesi.
Euomphalopterus sp.
Actinoceras keewatinensis.
Encrinurus sp.

2. Limestone, gray, fine grained, with many rounded masses showing concentric structure resembling stromatoporoids; exposed in the lower part of the bluff near the mouth of Shammattawa River and in the lower part of the ledge for 2 miles along Winisk River below the mouth of the Shammattawa; containing the following fossils:...................... 12

Streptelasma pygmæum var. *occidentale.*
Zaphrentis stokesi.
Favosites favosus.
Alveolites ? sp.
Stropheodonta acanthoptera.
Stropheodonta cf. *philomela.*
Schuchertella aff. *curvistriata.*
Orthis cf. *flabellites.*
Dalmanella elegantula.
Clorinda mesoplicata.
Camarotœchia ekwanensis.
Camaratœchia sp.
Glassia variabilis.
Atrypa cf. *reticularis.*
Rhynchospira lowi.
Hormotoma whiteavesi.
Hormotoma sp.
Euomphalus rotundus.
Eotomaria sp.
Strophostylus filicinctum.
Leperditia hisingeri var.

1. Limestone, gray, fine grained, thin bedded, with few fossils; exposed near the base of the bluff a short distance above the mouth of Shammattawa River... 8

Besides the fossils mentioned above, the following species were collected from loose fragments of Silurian limestone at this locality. These indicate the presence of the Ekwan River limestone farther up the river, but the strata from which they came were not seen.

Halysites catenulatus.
Trimerella borealis.
Meristina expansa.
Liospira stevensoni.
Megomphala robusta.
Trochonema sp.
Cf. *Pleurotomaria hoyi.*

FIGURE 1.—VIEW OF THE FINE-GRAINED, THIN-BEDDED LIMESTONE INCLINED ON THE FLANKS OF THE CORAL-REEF ROCK; EXPOSED ALONG SEVERN RIVER

FIGURE 2.—VIEW SHOWING THE UNSTRATIFIED IRREGULAR CHARACTER OF THE ATTAWAPISKAT CORAL-REEF ROCK; EXPOSED ALONG EKWAN RIVER

DOME OF CORAL-REEF ROCK, AND FINE-GRAINED LIMESTONE INCLINED ON THE FLANKS OF SUCH DOMES

Phanerotrema occidens ?
Tentaculites sp.
Cf. *Ctenodonta subovata.*
Phragmoceras cf. *whitneyi.*
Isochilina grandis var. *latimarginata.*

EKWAN RIVER SECTION

Several miles south of the Winisk, along Ekwan River, the higher formations of the Silurian limestone are well exposed. The lowest rocks seen along this river outcrop about 1½ miles above the mouth of the Matateto River, about 115 miles from the bay. Below this locality occasional outcrops are encountered down the river for a distance of about 80 miles. A detailed section of the strata exposed in the banks of Ekwan River is given below:

	Thickness in feet
Silurian limestone	
Niagaran series	
Attawapiskat coral reef	
7. Limestone coral reef, consisting of domes and ridges of stromatoporoids and coral rock the flanks of which are bordered by layers of fine-grained limestone similar in character to the reef rock exposed on Limestone Island and at the portage farther down the Severn River, with which horizon it corresponds; exposed at the portage at Strong Rapids and for several miles below this locality; containing the following fossils:	30

Streptelasma sp.
Diphyphyllum multicaule.
Cf. *Acervularia austini.*
Vesicularia cf. *major.*
Pycnostylus elegans.
Cystiphyllum niagarense.
Favosites favosus.
Favosites hisingeri.
Favosites cf. *occidens.*
Favosites sp.
Syringopora cf. *bifurcata.*
Heliolites cf. *interstincta.*
Heliolites cf. *subtubulata.*
Aphyllostylus gracilis.
Phœnopora keewatinensis.
Fenestella subarctica.
Stropheodonta sp.
Plectambonites cf. *transversalis.*
Orthis cf. *flabellites.*
Dalamanella elegantula.
Gypidula sp.

Thickness in feet

Clorinda mesoplicata.
Glassia variabilis.
Glassia variabilis var.
Atrypa cf. *reticularis.*
Spirifer cf. *crispus.*
Spirifer sp.
Reticularia septentrionalis.
Meristina expansa.
Ambonychia septentrionalis.
Ambonychia undulata.
Liospira stevensoni.
Salpingostoma boreale.
Megomphala robusta.
Gyronema brevispira.
Phycnomphalus colemani.
Platyceras compactum.
Diaphorostoma perforatum.
Strophostylus amplus.
Strophostylus inflatus.
Strophostylus cf. *filicinctus.*
Orthoceras sp.
Phragmoceras sp.
Illænus cf. *ioxus.*
Illænus sp.
Bronteus aquilonarius.
Bronteus ekwanensis.
Cf. *Amphilichas* sp.
Ceraurus sp.

6. Limestone, composed largely of coral reef rock between the domes and ridges of which layers of fine-grained, thin-bedded limestone are inclined at various angles; exposed at the portage at Strong Rapids and at the rapids one mile above the portage; containing the fossils named below:........................... 24

Zaphrentis patens.
Zaphrentis sp.
Pycnostylus guelphensis.
Favosites sp.
Trimerella ekwanensis.
Stropheodonta sp. 1
Stropheodonta sp. 2
Plectambonites cf. *transversalis.*
Gypidula sp.
Dalmanella elegantula.
Glassia variabilis.
Atrypa cf. *reticularis.*
Spirifer sp.
Reticularia septentrionalis.

	Thickness in feet
Meristina expansa.	
Ambonychia septentrionalis.	
Ambonychia undulata.	
Ambonychia sp.	
Mytilarca pernoides.	
Conocardium sp.	
Horomotoma whiteavesi.	
Strophostylus filicinctus.	
Orthoceras sp.	
Illænus sp.	
Bronteus sp.	
Leperditia phaseolus.	
Ekwan River limestone.	
5. Limestone, gray, fine grained, thinly and irregularly stratified; exposed 7 miles below Flint Rapids and about one mile farther down the river, where a small anticline appears in the river bank; containing few fossils	25
4. Limestone, gray, fine grained, coralline, containing numerous concretions and irregular patches of dark chert and stromotoporoid structures which form domes and irregular masses; exposed in the bed and banks of the river at Flint Rapids; containing the fossils named below:.............................	15 to 20
Streptelasma sp.	
Zaphrentis stokesi.	
Chonophyllum canadense.	
Ptychophyllum cf. *stokesi.*	
Diphyphyllum multicaule.	
Cystostylus infundibulum.	
Cystostylus typicus.	
Aphyllostylus gracilis.	
Tyrrellia severensis.	
Paleofavosites aspera.	
Favosites favosus.	
Favosites hisingeri.	
Alveolites niagarensis.	
Syringopora cf. *bifurcata.*	
Halysites catenulatus.	
Euomphalus rotundus.	
Euomphalopterus cf. *tyrrelli.*	
Actinoceras sp.	
Isochilina grandis var. *latimarginata.*	
A short gap in exposure	
3. Limestone, gray, cherty in the upper part; exposed in the south bank of the river one mile above Flint Rapids, where the strata dip gently downstream; containing the fossils named below:................	12 to 15

Thickness in feet

Zaphrentis patens.
Favosites favosus.
Favosites sp.
Syringopora bifurcata.
Halysites catenulatus.
Stropheodonta acanthoptera.
Stropheodonta cf. *philomela.*
Stropheodonta sp.
Orthis cf. flabellites.
Dalmanella elegantula.
Camarotœchia ekwanensis.
Cf. *Camarotœchia coalescens.*
Camarotœchia ? winiskensis.
Atrypa cf. *reticularis.*
Euomphalus rotundus.
Tentaculites sp.
Leperditia hisingeri var.

2. Limestone, gray, fine grained, thin bedded, containing *Trimerella ekwanensis* and several species of gastropods near the base; well exposed in the south bank of the river at the Upper Rapids and at the rapids next below; containing the following fossils:....... 15 to 20

Streptelasma pygmæum var. *occidentale.*
Streptelasma sp.
Favosites favosus.
Syringopora bifurcata.
Halysites catenulatus.
Lyellia sp.
Trimerella ekwanensis.
Stropheodonta acanthoptera.
Stropheodonta sp.
Orthis cf. *flabellites.*
Bellerophon sp.
Hormotoma whiteavesi.
Phanerotrema occidens ?
Euomphalus rotundus.
Euomphalopterus cf. *tyrrelli.*
Strophostylus filicincta.
Actinoceras keewatinensis.
Actinoceras sp.
Isochilina grandis var. *latimarginata.*

A gap in exposure

1. Limestone, buff, fine grained, dolomitic, in places mud cracked; without fossils; exposed in the south bank of the river between Matateto and Crooked rivers.. 6 to 8

From the study of fossils collected by Wilson,[15] Whiteaves has shown

[15] W. J. Wilson: Report on geology of Algoma and Thunder Bay districts. Geol. Survey of Canada, 1909, pp. 37 *ff*.

that Silurian rocks are present farther south on Little Current, Drowning, and other branches of the Albany River.

Fragments of yellow dolomite containing the fossils *Favosites favosus, Stropheodonta acanthoptera, Stropheodonta* sp., cf. *Virgiana decussata, Pterinea occidentalis,* and *Leperditia hisingeri* var. were found in the glacial drift along Nelson River 50 miles above the nearest exposure of Paleozoic rocks farther down that stream.

CORRELATION OF THE SILURIAN FORMATIONS OF THE HUDSON BAY REGION

In general.—The Port Nelson and Severn River limestones in the Hudson Bay region are thought to represent the pre-Niagaran or Alexandrian series of the Silurian system, while the Ekwan River limestone and the Attawapiskat coral reef are referred to the Niagaran.

Port Nelson limestone.—The most characteristic fossil of the Port Nelson limestone in the Hudson Bay region is *Virgiana decussata.* This species also occurs abundantly in the basal Silurian rocks at the Grand Rapids of Saskatchewan River,[16] and it is practically certain that the strata from which they came in the two regions represent the same stratigraphic horizon. The Port Nelson limestone includes all of the Silurian strata in this region below the top of the layers containing *Virgiana decussata.* In another paper[17] the senior writer has shown that the lower part of the Silurian limestone in the Hudson Bay region, containing shells of *Virgiana decussata,* corresponds with the zone containing numerous shells of this species at the Grand Rapids of Saskatchewan River, and was to be correlated with the basal part of the Stonewall limestone of Manitoba and with the upper part of the Mayville limestone in Wisconsin and northern Michigan. It probably represents the same period of deposition as the early Silurian strata of western and northwestern North America, which contain numerous shells of *Virgiana* that have previously been referred to the genus *Conchidium* or *Pentamerus.*

Severn River limestone.—The Severn River limestone clearly corresponds with the Silurian limestone described by Hume from the Lake Timiskaming region and correctly correlated by him with the Cataract formation of southern Ontario. It corresponds with that part of the Stonewall limestone of the Grand Rapids of Saskatchewan region above the zone of *Virgiana decussata* and is considered the equivalent of the Hendricks and Fiborn limestones of northern Michigan. The correlation

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[16] E. M. Kindle: Notes on the geology and paleontology of the lower Saskatchewan River valley. Geol. Survey of Canada, Mus. Bull. no. 21, Geological series no. 30, October 14, 1915, p. 16.

[17] T. E. Savage: Correlation of early Silurian rocks of the Hudson Bay region. Journal of Geology, vol. 26, no. 4, 1918, pp. 334-340.

described above indicates the age of the Severn River limestone as about that of the Cataract formation of Ontario, which probably corresponds in age to the early Brassfield or Sexton Creek time. The relations of the province in which the Severn River limestone was deposited to the other North American marine provinces of this time, as conceived by the writers, is shown on the paleogeographic map, figure 2.

Ekwan River limestone.—The Ekwan River limestone doubtless corresponds in age to the lower or middle part, or to both the lower and middle parts, of the Lockport, or Louisville, limestone of the Mississippi Valley and New York State, but it belongs to a different province of deposition, in which the fauna was so different as to make direct correlation with any horizon of the Lockport unusually difficult. It appears to be younger than the Clinton of New York, and to be equivalent in time to the lower or middle Lockport limestone of the Niagaran series, as the succeeding Silurian rocks in the Hudson Bay region are thought to represent late Lockport time.

Attawapiskat coral reef.—The Attawapiskat coral reef is thought to correspond, in part at least, with the reef rock referred to by William Logan,[18] and more recently described by Williams[19] as the Eramosa beds, which occurs in the upper part of the "Lockport member of the Niagara" in southern Ontario.

While the Ekwan River limestone and the Attawapiskat coral reef are thought to correspond in time to some part of the Niagaran epoch, the conspicuous feature of the Niagaran rocks in the Hudson Bay region is the great difference in the character of their faunas compared with that of the Niagaran in the Mississippi Valley and New York. Very few of the typical Niagaran species of the latter areas are present in the Niagaran rocks of the Hudson Bay region. Not a single species of Niagaran brachiopods is common to the Hudson Bay region and the Iowa and Illinois region of the Mississippi Valley, and no species of Echinodermata, Mollusca, or Arthropoda found in one of these areas has been definitely identified in the other. A few of the Silurian corals that have an almost world-wide distribution appear in both regions, but many of the coral species present in the northern area do not appear in the southern.

The Niagaran fauna of Illinois and Iowa resembles that of the Niagaran of New York so much more closely than either one of these resembles the Niagaran of the Hudson Bay region that it seems much more probable that the Niagaran fauna of Illinois and Iowa came from the

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[18] William Logan: Geol. Survey of Canada. Report of progress to 1863, p. 337.

[19] M. Y. Williams: An Eurypterid horizon in the Niagara formation of Ontario. Geol. Survey of Canada, Mus. Bull. no. 20, Geological series no. 29, 1915.

FIGURE 2.—*Generalized Map of North America during Period of Deposition of the Port Nelson and Severn River Limestone*

Late Edgewood and early Cataract or Brassfield time. Lined areas represent seas.

east, or Atlantic, realm, across New York, than that it entered the continent from the Arctic region by way of Hudson Bay.

The Niagaran fauna of the Hudson Bay region certainly reached as far south as southern Ontario, but appears not to have advanced far into the United States. The Niagaran fauna of Wisconsin, like the earlier Silurian in this region, may be of northern origin, as it resembles that of the Niagaran of the Hudson Bay region more closely than does that of the Niagaran of Illinois, Iowa, and New York, as is shown by the occurrence of such unusual coral species as *Cystostylus infundibulus, C. typicus,* and *Pycnostylus guelphensis* in the Niagaran of both the Wisconsin and Hudson Bay regions. The province or basin in which the Niagaran rocks of Illinois and New York were deposited must have been completely separated either geographically or in time from that of the more northern basin, which contained the Niagaran faunas of the Hudson Bay and Ontario regions, so that little or no opportunity was permitted for the intermigration of any of the many species that inhabited these different basins. The paleogeographic map, figure 3, will show the views of the writers regarding the relations of the geologic provinces of North America during this part of the Niagaran epoch.

Devonian Rocks in the Hudson and James Bay Region

EARLIER STUDIES

For our previous knowledge of the Devonian rocks in this region we are indebted largely to the work of Robert Bell and W. A. Parks. In a report on the east coast of Hudson Bay, Bell[20] lists, on the authority of Whiteaves, several species of Devonian fossils that were collected between the long portage of the Missinaibi branch of Moose River and Moose Factory. These species are thought to indicate the Upper Devonian age of the strata and are similar to those occurring in the Devonian rocks along Abitibi River. In a report of an exploration of portions of Attawapiskat and Albany rivers, Bell[21] gives a list of Devonian fossils collected along Albany River for some distance above Fort Albany. These were identified by Whiteaves, who considered them of Lower Devonian age. In a later report Bell[22] lists the species of fossils from the Devonian rocks along Kwataboahegan River and also gives a list of species collected along the Abitibi.

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[20] Robert Bell: Report on an exploration of the east coast of Hudson Bay in 1877. Geol. Survey of Canada, 1879, Rept. C, pp. 5*c* to 6*c*.

[21] Robert Bell: Geol. Survey of Canada, Summary Rept., 1886, p. 33G.

[22] Robert Bell: Geol. Survey of Canada, Summary Rept., 1902 and 1903, pp. 230A and 236A.

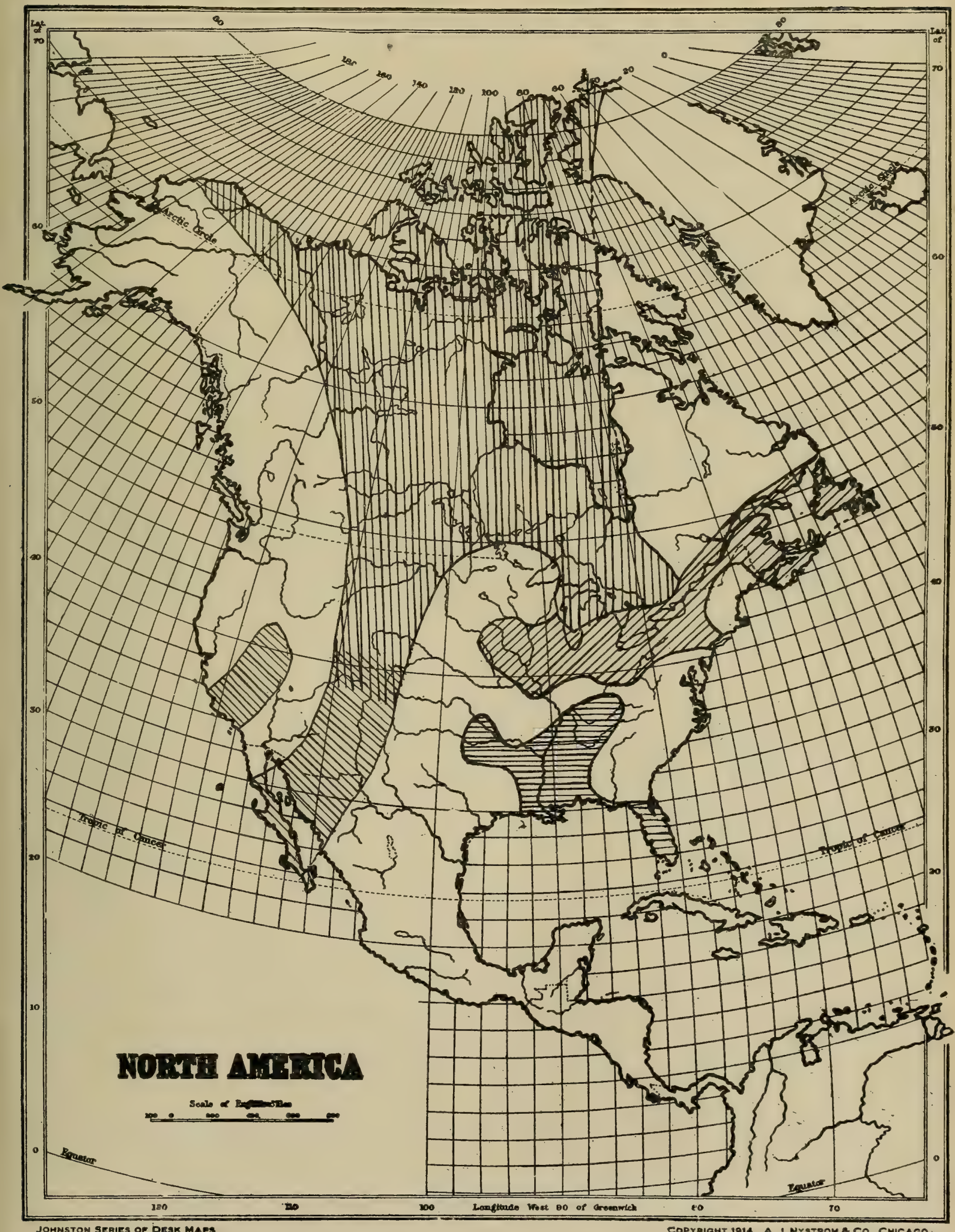

FIGURE 3.—*Generalized Map of North America during Period of Deposition of Ekwan River and Attawapiskat Limestones*

Louisville or Lockport time. Lined areas represent seas.

In a paper on the Nipissing and Algoma boundary, Parks[23] describes the rocks occurring along the Abitibi and Little Abitibi rivers and lists the species of fossils collected along these streams. Some of the species from the latter river indicate a possible Devonian horizon lower than the fossiliferous Devonian along the Abitibi.

More recently Parks has published a more complete list of the Devonian fossils found along Kwataboahegan River,[24] which includes certain species that led him to conclude that the limestones exposed along that river were to be correlated with the lower part of the Onondaga of the New York section.

Fossils of Devonian age were collected from limestone boulders in the glacial drift along the banks of Nelson River about 20 miles below the Split Lake post of the Hudson Bay Company and 50 miles above the first exposure of Paleozoic rocks farther down the river. The species included *Striatopora* sp., *Chonetes* sp., *Productella* sp., *Gypidula* near *comis, Atrypa missouriensis, A. spinosa,* and *Spirifer subvaricosa.* Silurian fossils were also found in some of the limestone boulders in this locality. These fossils would indicate that outliers of Devonian and Silurian rocks were probably present in pre-Pleistocene time in places north and east of the great center of accumulation of the Keewatin ice-sheet. However, no Devonian rocks in place have been reported in this region north of the basin of Albany River.

STRUCTURE OF THE STRATA

The Devonian rocks along Abitibi and Moose are more or less undulating, but have a general dip toward the north at a low angle. In places local folds disturb the prevailing inclination of the strata. One of the most prominent folds is exposed on the west bank of Abitibi River near the middle of Long Rapids, about 55 miles above its mouth, where a rather steep syncline crosses the valley in a nearly east-west direction and carries the Devonian limestone below the bed of the river. A thickness of about 55 feet of Upper Devonian *Sporangites*-bearing shale is here exposed above the level of low water for a distance of several rods. Farther up the same river, in the vicinity of Coral Portage, the lower part of the section is cut by dikes and small stacks of basaltic igneous rock. Similar intrusives occur in sandstones and conglomerates of a lower horizon at the Sextant Rapids, 2½ miles farther up the river.

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[23] W. A. Parks: Ontario Bureau of Mines, vol. viii, pt. 2, 1899, pp. 187 and 188.

[24] W. A. Parks: 13th Rept. of the Bureau of Mines, Ontario, Canada, pt. 1, 1904, pp. 180 to 191.

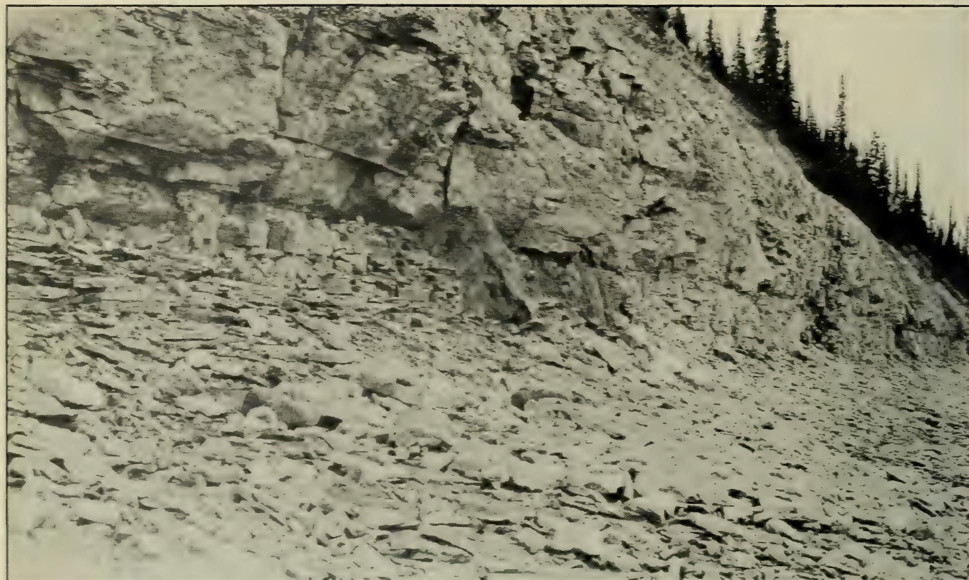

FIGURE 1.—UPPER PART OF SEVERN RIVER LIMESTONE AND LOWER PORTION OF EKWAN RIVER LIMESTONE: EXPOSED ALONG SEVERN RIVER

FIGURE 2.—DEVONIAN LIMESTONE EXPOSED IN THE SOUTH BANK OF ABITIBI RIVER, AT ITS JUNCTION WITH THE MOOSE RIVER

SILURIAN AND DEVONIAN LIMESTONES ALONG SEVERN AND ABITIBI RIVERS

DETAILED SECTION OF DEVONIAN STRATA EXPOSED ALONG ABITIBI RIVER

	Thickness in feet
Devonian system	
Upper Devonian series	
Long Rapids shale	
13. Shale, in alternating layers of gray and dark color; exposed in the west bank of river, about the middle of Long Rapids....................................	20
12. Shale, black, somewhat laminated, containing numerous spores of *Sporangites huronense;* exposed in the west bank where a syncline crosses the river valley near the middle of Long Rapids...........	35
Abitibi River limestone—about 110 feet	
11. Shale, calcareous, in layers 4 to 10 inches thick, alternating with irregular nodular layers of about equal thickness; exposed beneath the black shale, number 12 above, from which it is separated by a sedimentary break; containing the fossils listed below:	8
Leptostrophia cf. *perplana.*	
Schuchertella chemungensis var.	
Productella cf. *productoides.*	
Schizophoria iowensis.	
Leiorhynchus near *globuliformis.*	
Leiorhynchus near *kelloggi.*	
Leiorhynchus aff. *mesacostalis.*	
Atrypa missouriensis.	
Atrypa reticularis.	
Cyrtina hamiltonensis var.	
Cyrtina hamiltonensis.	
Spirifer near *subvaricosus.*	
Delthyris sculptilis.	
Reticularia aff. *lævis.*	
Athyris fultonensis.	
10. Limestone, irregularly bedded, partly dolomitic, with few or no fossils; exposed in the upper part of Long Rapids and also at the mouth of Abitibi River and near the mouth of the Kwataboahegan River..	18
9. Limestone, shaly, or calcareous shale, with few or no fossils; exposed along the river bank near the upper end of Long Rapids......................	3
8. Dolomite, brown, in thin layers, the lower 3 feet a distinct coral reef; containing the species listed below; exposed a short distance above the outcrops of 9 and 10 above............................	12
Acervularia davidsoni.	
Acervularia near *profunda*	
Favosites alpenensis.	
Alveolites sp.	
Aulopora sp.	
Ceratopora sp.	

Thickness in feet

Atrypa reticularis.
Athyris fultonensis.

A short gap in exposure

7. Limestone, brown, nodular, with very many shells of *Atrypa reticularis* var.; exposed in the west bank near the head of Long Rapids and on the island opposite; this is thought to represent the horizon of the gypsum along Moose River 28

A short gap in exposure

6. Dolomite, brown, massive, rather soft and vesicular, well exposed on both sides of the river at the foot of Coral Portage; containing the fossils listed below: 28
    Streptelasma cf. *prolifica.*
    Cyathophyllum sp. (large coralla).
    Heliophyllum aff. *halli.*
    Heliophyllum sp. (compound coralla).
    Phillipsastræa verneuili.
    Diphyphyllum cf. *simcoense.*
    Cystiphyllum cf. *vesiculosum.*
    Favosites basaltica.
    Favosites radiciformis.
    Favosites turbinata.
    Favosites sp.
    Alveolites squamosus.
    Syringopora maclurea.
    Syringopora nobilis.
    Syringopora sp. (with small corallites).
    Stropheodonta demissa.
    Schizophoria iowensis.

5. Alternating layers of bluish gray shale and shaly limestone, each 5 to 8 inches thick, the more pure limestone layers containing the fossils listed below; exposed between Coral and Sextant portages. 21
    Stropheodonta demissa.
    Conocardium cf. *trigonale.*

Middle Devonian series (?)

Sextant sandstone and shale

4. Conglomerate, gray, containing small pebbles and a considerable amount of sand, cemented with calcium carbonate; exposed at Sextant Rapids 1½
3. Shale, sandy, red, exposed at Sextant Rapids .... 8 to 10
2. Sandstone, soft, red, poorly sorted, and irregularly bedded, arkosic, bearing several thin sills of basalt; exposed at Sextant Rapids 27
1. Conglomeratic sandstone, with intruded sills of basalt; well exposed in the west bank of the river a short distance above Sextant Rapids; to contact with basic intrusion in the bed of the river 35

CORRELATION OF THE DEVONIAN STRATA EXPOSED ALONG ABITIBI RIVER

Sextant sandstone and shale.—On account of the absence of fossils and the indecisive evidence furnished by their stratigraphic relations, the age and correlation of the Sextant sandstone and shale outcropping in the vicinity of Sextant Portage along Abitibi River can only be provisionally determined. From their stratigraphic position, it is known that they are older than the Devonian strata included in the Abitibi River limestone. The generally red color of these rocks and the arkosic character of some of the sands indicate that they were deposited under arid climatal conditions, and suggest that they may possibly correspond in age with some of the salt-bearing Devonian rocks which furnish the salt in the salt springs of western Manitoba. However, it is recognized that gypsum deposits, indicating similar conditions of aridity, also occur in Devonian strata along Moose River, but the latter are thought to correspond in age to a higher horizon in the Abitibi River limestone. In the absence of definite evidence regarding the age of these sandstones and shales, they are tentatively referred to the Middle Devonian.

Abitibi River limestone.—The fauna of the Abitibi River limestone appears to be more closely related to that of the Upper Devonian of the Manitoba and Iowa regions—the Interior Continental province of Williams—than to that of any Devonian horizon in the Eastern, or New York, section. This fauna contains a relatively larger proportion of compound corals and fewer simple cup corals than usually occur in the New York Hamilton.

Furthermore, the characters of the fossil called *Stropheodonta demissa* are those of species found in the Interior Continental province. *Favosites alpenensis, Schizophoria iowensis, Athyris fultonensis,* and *Atrypa missouriensis* are characteristic species of the Devonian of this Western region. From these considerations it is thought that the Abitibi River limestone is to be correlated with some part of the late Devonian of the Interior Continental province, as developed in Iowa and western Manitoba, rather than to any part of the late Devonian section of the Eastern, or New York, province, with some part of which these strata doubtless correspond in age.

Compared with the Devonian fauna of Manitoba, the absence of *Stringocephalus burtoni* and several of its associates is conspicuous, and the Abitibi River limestone fauna corresponds more closely with that of the youngest formation (Manitoban of Tyrrell) than to that of either of the older Devonian formations of western Manitoba, as does also the late Middle Devonian fauna of Iowa. After the Winnipegosan dolomite which contains the *Stringocephalus burtoni* fauna had been deposited in this

FIGURE 4.—*Generalized Map of North America during Period of Deposition of Abitibi River Limestone*

Early Upper Devonian. Lined areas represent seas.

region, there probably occurred a great expansion of the sea in the Interior Continental province. During Manitoban time the Arctic Sea advanced as far south as Iowa, northwest Illinois, and northern Missouri and spread eastward as far as the James Bay and Abitibi River region about as shown in figure 4. This great expansion prevailed also in the late Devonian during the time of deposition of the *Sporangites*-bearing, Long Rapids shale.

Long Rapids shale.—The only fossils found in the Long Rapids shale are the spores of a species of a pteridophyte plant known as *Sporangites huronense,* which occur in great abundance throughout the black shale. Numerous spores of this species are also characteristic of the Sweetland Creek shale (usually referred to the Upper Devonian) of Iowa and Illinois, which is known to extend as far north as Chicago and Milwaukee. It may be that the Long Rapids shale is to be correlated with the Sweetland Creek shale farther south, the latter then being a representative of the Long Rapids deposit.

Professor Parks has reported several species of Devonian fossils from Kwataboahegan River and Little Abitibi River that do not appear in the foregoing lists and that seem to indicate a fauna older than that found along Abitibi River. There seems no doubt that other fossiliferous Devonian horizons are present in the James Bay region than those found along the Abitibi and Moose rivers. It is possible that a part or all the older Devonian strata indicated by the fossils reported by Parks from Kwataboahegan and Little Abitibi rivers may be represented in the Abitibi River section by the unfossiliferous sandstone and shale of the Sextant formation, which is older than the Abitibi River limestone. It is also recognized that in other places in the James Bay region a fossiliferous limestone, not represented in the Abitibi River section, may be present at a horizon lower than that of the sandstone and conglomerate occurring in the basal part of the Devonian along Abitibi. The detailed description of the relation and correlation of the Devonian rocks in this region older than the Abitibi River limestone must be postponed until a more detailed study of the rocks exposed along the Kwataboahegan and other rivers tributary to the Moose and Albany rivers can be made.

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PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY

CAMARASAURUS, AMPHICŒLIAS, AND OTHER SAUROPODS OF COPE[1]

BY HENRY FAIRFIELD OSBORN AND CHARLES CRAIG MOOK

(*Presented before the Paleontological Society December 29, 1918*)

CONTENTS

INTRODUCTION

In 1902 the Cope Collection of Fossil Reptiles was presented to the American Museum of Natural History by President Morris K. Jesup. It included all of Cope's types and other dinosaur material of Morrison age from the vicinity of Canyon City, Colorado. Several of these types antedated in definition Marsh's types from beds of similar age. Cope's references were full, but accompanied by few figures; Marsh's came later and were adequately illustrated. Marsh also issued, in the publications of the United States Geological Survey, two more or less complete sum-

[1] Manuscript received by the Secretary of the Society March 12, 1919.
Henry Fairfield Osborn and Charles Craig Mook: Introduction to a joint memoir entitled "*Camarasaurus, Amphicœlias*, and other sauropods of Cope." In preparation. American Museum of Natural History.

maries of the characters of these animals, which were fully illustrated and widely distributed; consequently they became well established in the literature, while Cope's are still unrecognized and imperfectly known. Our object has been to describe and determine as fully as possible Cope's types, especially of the Opisthocœlia, the most important of which is that of *Camarasaurus*. This generic name antedates *Morosaurus* Marsh, with which it is considered congeneric, by about one year.

The fugitive descriptions and determinations by Cope, Osborn, Riggs, and Mook may now be replaced by thorough descriptions and illustrations, in which the characters of the genus *Camarasaurus* are determined in great detail, so far as the nature of the material will permit. All the type material, including the types of six genera and eleven species, has been figured, and these animals, practically unknown since their original mention forty years ago, have now been brought to light.

Occurrence and collecting of Material

ORIGINAL DISCOVERY AND COLLECTING

In the spring of 1877 Mr. O. W. Lucas, superintendent of public schools in Canyon City, Colorado, discovered some large fossil bones, which he sent to Prof. Edward D. Cope. The date of this discovery is not definitely known, but it appears to have been some time in March. From the first specimens which reached the Cope Museum in Philadelphia, Cope made his original description of *Camarasaurus* and founded the genus; this description was published August 23, 1877. The name *Camarasaurus*, or "chambered saurian," was given in reference to the cavernous nature of the centra of the cervical and dorsal vertebræ, in connection with the lateral cavities now known as pleurocœlia. After receiving the original bones, Cope employed collectors who gathered more material, all of which is now in the American Museum.

SUBSEQUENT COLLECTING

The amount of material collected by Cope's parties was very large. It was not all prepared at once, but a considerable amount of it was cleaned up by Jacob Geismar under Professor Cope's direction. In 1877 a reconstruction of the skeleton of *Camarasaurus* was made by Dr. John Ryder, under the direction of Professor Cope. This reconstruction, the first ever made of an opisthocœlous dinosaur, was natural size and embodied representations of the remains of a number of individuals; it was over fifty feet in length. It was exhibited at a meeting of the American Philosophical Society, on December 21, 1877, and since has been exhibited a

number of times at the American Museum (where it is now preserved) and elsewhere. A greatly reduced copy of it was published by Mook in 1914.[2]

After the collecting of the material which formed the basis of the above-mentioned reconstruction, Cope's collectors sent in more material. This collecting was continued until 1880.

GEOLOGICAL DESCRIPTION OF THE CANYON CITY DINOSAUR LOCALITY

All the bones were found in the uppermost beds of the Morrison formation near Garden Park, about 8½ miles north to northeast of Canyon City, Colorado. The Morrison in this locality is about 320 feet thick and is a member of a triangular block of sedimentary rocks which is nearly surrounded by the ancient crystallines. The apex of the triangle is toward the north. The crystalline rocks bound the block on the east, north, and west; toward the south the block merges into the sediments of the plains. The block is partly faulted against the crystallines and partly folded down alongside of them. Detailed information regarding the general geology of the region is available in the Pikes Peak Folio[3] of the United States Geological Survey's Geological Atlas.

The Morrison formation is composed lithologically of thin limestone bands, sandstone beds, usually showing cross-bedding, but chiefly of fine grits known as "joint-clays." This formation is one of great areal extent and of comparatively small thickness. It has been interpreted as the result of deposition of sediments, mainly by rivers, but partly by wind, on a broad flat plain of rather low altitude. The conditions of its deposition evidently provided broad areas of marshy country, with lakes, interlacing streams, and flat interstream areas. Such conditions favored the development of the Opisthocœlia and other branches of dinosaurs. The age of the formation has been variously interpreted as Jurassic, Jura-Cretaceous, and Comanchean. No opinion, however, upon that subject is stated at the present time. The formation has recently been discussed by Lee,[4] Mook,[5] and Schuchert,[6] to whose articles reference is made for further information.

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[2] Charles C. Mook: Notes on *Camarasaurus* Cope. Ann. New York Acad. Sci., vol. xxiv, May 21, 1914, pp. 19-22, 1 fig.

[3] Whitman Cross: Pikes Peak Folio: U. S. Geol. Survey, Geol. Atlas, Folio 7, 1894, 6 pp., 5 maps.

[4] Willis T. Lee: Reasons for regarding the Morrison as an introductory Cretaceous formation. Bull. Geol. Soc. Am., vol. 26, 1915, pp. 303-314.

[5] Charles C. Mook: A study of the Morrison formation. Ann. N. Y. Acad. Sci., vol. xxvii, 1916, pp. 39-191, 94 figs., pl. vi.

[6] Charles Schuchert: Age of the American Morrison and East African Tendaguru formations. Bull. Geol. Soc. Am., vol. 29, 1918, pp. 245-248.

THE QUARRIES

Unfortunately the quarry records of the Cope Canyon City material have been lost; no quarry diagrams are mentioned in any of Cope's descriptions and it is unlikely that any were made. Two large quarries are known to have existed and their location is known at the present time.

One of these is situated almost at the crest of the escarpment which forms the west boundary of Garden Park and near the base of a small conical hill locally known as the "Nipple." It is not very definitely marked, but traces of the work of excavation by Cope's collectors and others mark its site. This quarry is called **Cope Quarry No. 2.** The matrix is largely grayish and it is likely that it furnished most of the bones which are known collectively as the **yellow series,** although this is not certain. Some of the matrix is neither gray nor yellow, and it is possible that certain of the yellow bones may have come from the other quarry. The value, therefore, of the color of the matrix, in determining the field association of the bones, is limited. Variation in color depends on the condition of the iron oxide of the matrix and probably also on the original conditions of decay of the animal tissue. The quarry was reworked by Mr. J. B. Hatcher for the Carnegie Museum in 1901.

Another large quarry is situated about 500 yards west to southwest of the "Nipple," a considerable distance from the edge of the escarpment. This quarry is called **Cope Quarry No. 1.** Here the Morrison is capped by the Purgatoire sandstone and the quarry site is very definitely marked by a great excavation. The matrix is chiefly reddish to brownish, and *probably* most of the bones of a reddish color, collectively known as the **red series,** came from this quarry.

There must have been at least one more quarry in this vicinity which furnished some of the opisthocœlous material, but the nature and the location of it are not known; indeed, the types of *Amphicœlias altus* and *A. latus* may have come from this quarry, about which no reliable information is available. All of these quarries are located a short distance north of the Marsh-Hatcher quarry, which yielded the types of *Diplodocus longus* Marsh, *Haplocanthosaurus priscus,* and *H. utterbacki* Hatcher. The Marsh-Hatcher quarry was excavated at a lower geologic level than the Cope quarries.

Original Descriptions of Opisthocœlia by Cope

The chronologic sequence of the establishment of the genera and species, with a brief statement of their present determination, may be summarized as follows:

Genus Species	Original date	Present determination
I. *Camarasaurus*	August 23, 1877	*Camarasaurus*
1. *C. supremus*[7]	August 23, 1877	*C. supremus*
2. *C. leptodirus*	June, 1879	*C. supremus*
II. *Caulodon*	November 21, 1877	Provisionally, *Camarasaurus*
3. *C. diversidens*[7]	November 21, 1877	Provisionally, *C. supremus*
4. *C. leptoganus*	January 10, 1878	Provisionally, *C. supremus*
III. *Tichosteus*	November 21, 1877	Indeterminate
5. *T. lucasanus*[7]	November 21, 1877	Indeterminate
6. *T. æquifacies*	May 3, 1878	Indeterminate
IV. *Amphicœlias*	December 10, 1877	*Amphicœlias*
7. *A. altus*[7]	December 10, 1877	*A. altus*
8. *A. latus*	December 10, 1877	Provisionally, *C. supremus*
9. *A. fragillimus*	August, 1878	Indeterminate
V. *Symphyrophus*	January, 1878	Indeterminate
10. *S. musculosus*[7]	January, 1878	Indeterminate
VI. *Epanterias*	June, 1878	Provisionally, carnivore
11. *E. amplexus*[7]	June, 1878	Provisionally, carnivore

Preparation and Research in the American Museum

ACQUISITION

The Cope Collection of Fossil Reptiles had been examined in Philadelphia by Dr. W. D. Matthew and was transferred to the American Museum under his direction. The preparation of the material was made by Messrs. Kaison, Charles and Otto Falkenbach, Lang, Christman, Hoover, Brickner, Carr, and Horne.

RESEARCH IN 1904

Doctor Matthew went over the material, under the direction of Professor Osborn, and catalogued and identified it so far as was possible with the aid of the records available, distinguishing the material obtained in the earlier collecting, in 1877, by Superintendent Lucas, from that obtained in the later collecting, in 1880, under Mr. Ira H. Lucas. Subsequently Professor Osborn and Dr. W. K. Gregory made a further study of the vertebræ and arranged them provisionally into series, using, in addition to the previous records, the color of the bones, the bones of the

[7] Genotype.

red series apparently having come from a different quarry than those of the yellow series. The red bones probably came from Cope Quarry No. 1, and the yellow from Cope Quarry No. 2. The limitations of color in determining the original association of bones have been indicated above. The bones of the earlier collection were given the number 5760, with variations according to their identification as individuals, such as 5760′ and 5760″, and probably were mostly from Quarry No. 1; the bones of the later collection were given the base number 5761, with a further modification into 5761-*a* for a presumably different individual than the rest of 5761, and were probably from Quarry No. 2.

In connection with this work, which was carried on in 1904, Mr. Rudolph Weber, then artist of the Department of Vertebrate Paleontology, made line drawings of many of the vertebræ. In 1906 some wash drawings of the skull material were made by Mr. Erwin S. Christman. These illustrations were originally prepared for the United States Geological Survey Monograph on the Sauropoda, in course of preparation by Professor Osborn. The cost of preparation of these drawings was borne by the Survey.

RESEARCH IN 1912-1919

In 1912 work on the Cope Opisthocœlia material was renewed as part of the preparation of the Sauropoda Monograph, which was being prepared for the Survey by Professor Osborn. This work was undertaken by the present junior author under the direction of the senior author. The entire Cope Collection of Opisthocœlia from Canyon City was studied, among other material, with the object of separating the vertebræ and limb bones referable to *Camarasaurus, Amphicœlias,* and the other Cope genera and arranging them in series *similar in size, proportion, and color*, as well as determining the characters of *Camarasaurus* and *Amphicœlias* and the less known genera. To a considerable extent this work consisted in verification of the previous work by Doctor Matthew and Doctor Gregory, in modification of their results, in a few cases, and in expanding them to meet the present needs.

This research has terminated in the arrangement of the vertebræ and ribs in *morphological series,* which may represent originally distinct individuals or they may not. The attempt was made to associate the bones of single individuals so far as practicable, but in many cases evidence for this was insufficient and in such cases an effort was made to assemble series that would be reasonably constituted in a morphological sense. The arrangement of the bones in these series is as accurate as it could be made, in view of the distorted, sometimes incomplete, and badly mixed character

of the material. The pairing of the girdle and limb bones was similarly undertaken, though no attempt was made to pair the ribs. In a few cases it has been possible to determine the relation of some of the girdle and limb bones with the vertebræ, but in most cases the original association is still unknown, though their possible association is very evident.

CARNIVOROUS DINOSAUR MATERIAL AND TYPES

Associated with typical theropod remains in the type of *Epanterias amplexus* are some bones of a large opisthocœlian. It is possible, if not probable, that the types of *Tichosteus lucasanus* and *T. æquifacies,* also of *Symphyrophus musculosus,* may be referable to the Theropoda. There are some ribs among these which certainly do not agree in characters with the majority of camarasaur ribs and do resemble those of the Theropoda. They may be provisionally referred to a large member of the Theropoda. Cope's type of *Lœlaps trihedrodon* and of *Hypsirophus discurus* were also collected at this locality. The former of these is certainly a therapod; the position of the latter is uncertain.

CHARACTERS OF THE GENUS CAMARASAURUS

The results of the investigations described above include determinations of the generic characters of *Camarasaurus* and *Amphicœlias,* so far as these characters are determinable from the material in the collection. The genus *Camarasaurus* is characterized by massive proportions. Throughout the skeleton, with the single exception of the ischium, the bones are stoutly constructed.

The cervical vertebræ have divided spines; otherwise they are not characteristic. They resemble very closely the cervicals of *Apatosaurus* (syn. *Brontosaurus*).

The dorsal vertebræ are characteristic. In addition to their general stoutness, the dorsals possess a number of diagnostic characters. The spines are low and broad. They possess a distinct type of lamination of their own, somewhat different from that of any of the other sauropod genera. The spines of the anterior dorsals are divided as in *Apatosaurus* and *Diplodocus,* and the posterior dorsal spines are single, as in those genera. There is a gradual transition from completely divided spines to single spines, however, contrasting with the relatively abrupt change in *Apatosaurus.* The spine of dorsal 7 is single or very slightly notched in *Camarasaurus,* whereas in the column of *Diplodocus* the division persists, to an appreciable extent, as far back as dorsal 9.

The zygapophyses are large. In the anterior dorsal region they are far

apart. They are first noted in the series in the articulation of dorsal 3 with dorsal 4.

The diapophyses, especially in the anterior region, are long. The parapophyses are low in position in the first three dorsals, posterior to which they are situated at a constant level.

The dorsal centra are all of medium length, the anterior ones being little longer than those nearer the sacrum. All of them are distinctly opisthocœlous, contrasting with *Apatosaurus* and *Diplodocus*, in which there is an abrupt change from strongly opisthocœlous anterior dorsal centra to distinctly platycœlous centra farther back.

The sacrum is characterized by short spines and by a tendency toward retardation in the inclusion of the vertebra immediately posterior to dorsal 10 in the sacrum itself as a functional dorsosacral.

The caudal series is distinguished from those of other sauropod genera by its short spines with expanded summits, the relatively slight development of the caudal ribs, and probably, but not certainly, by the absence of a distal whip-lash.

The scapula is large and massive. It is expanded at both ends. The coracoid is subcircular in outline; it is more distinctly rounded than that of *Apatosaurus*, but less so than that of *Diplodocus*.

The fore limb is not especially characteristic except in small details. It resembles that of *Apatosaurus*.

The ischium is one of the characteristic bones of the genus. In contrast with the rest of the skeleton, it is slender in form and has a long shaft, differing in regard to the latter character from *Apatosaurus* and *Diplodocus*. The pubis is very massive. It is somewhat more angular in outline than that of *Apatosaurus*, and its median border involves a greater degree of twisting.

The vertebral formula is not definitely known. It is probably slightly variable. As interpreted, it is: cervicals, 13; dorsals, 10; sacrum, 5 (dorsosacral + 3 primary sacrals + caudosacrals); caudals, 53. Another interpretation is: cervicals, 13; dorsals, 10; sacrum, 4 (3 primary sacrals + caudosacral); caudals, 53.

SYNONYMY OF CAMARASAURUS COPE AND MOROSAURUS MARSH

In 1898 the synonymy of *Morosaurus* Marsh with *Camarasaurus* Cope was suggested by Osborn[8]; in 1902 this view was favored by Riggs[9]; in

[8] Henry Fairfield Osborn: Additional characters of the great herbivorous dinosaur, *Camarasaurus*. Bull. Amer. Mus. Nat. Hist., vol. x, art. xii, June 4, 1898, pp. 219-233.

[9] Elmer S. Riggs: The fore legs and pectoral girdle of *Morosaurus*; with a note on the genus *Camarosaurus*. Field Col. Mus. Pub. 63, Geol. Ser., vol. i, no. 10, October, 1901, pp. 275-281, pls. xl, xli, xlii.

1914 it was definitely adopted by Mook.[10] At present *Morosaurus* is considered to be a synonym of *Camarasaurus,* Cope's term having priority and therefore being valid.

The basis for this conclusion is the following group of facts: both are massive in proportions, though different in size; both the remains of *Camarasaurus* herein described and those of the type specimens of Marsh's various species of *Morosaurus* have similar outlines to the bones of the skull, so far as these are available for comparison; the teeth are likewise similar; the cervical vertebræ, especially the axis, are practically identical in form; the dorsal vertebræ have similar outlines and proportions and are composed of essentially the same laminar elements and cavities; they have short spines, the division of the spines is similar, and the centra exhibit the same kind of opisthocœlous articulations; the sacrum in each possesses short spines of similar form and composition; also a tendency toward retardation in the inclusion of the dorsosacral in the sacrum; the caudal vertebræ have similar spines, similar centra, and similar slightly retarded development of caudal ribs; the scapula and coracoid are almost identical in outline and arrangement of parts; the ischia are slender, both actually and in proportion to the other parts of the skeleton, having little resemblance to other opisthocœlous ischia; the pubes are very angular in outline and exhibit a similar form of twisting on the median borders; the limb-bone proportions are similar, so far as direct comparison is possible.

The difference in size between the *Camarasaurus* remains now described and those of the Marsh species is largely due to age distinctions.

CHARACTERS OF THE GENUS AMPHICŒLIAS

Amphicœlias is more slender than *Camarasaurus;* its remains resemble those of *Diplodocus,* but are somewhat larger than any known *Diplodocus* and are somewhat more strongly constructed.

The anterior dorsal vertebræ possess divided spines; the spines of those near the sacrum are single. The latter possess double pre- and post-spinal laminæ. The posterior dorsal centra are platycœlous to amphicœlous, contrasting with the opisthocœlous centra of the posterior dorsal vertebræ of *Camarasaurus.* The femur is long and slender.

The following characters are inferred from material provisionally referred to the genus: scapula very large, resembling that of *Diplodocus* in outline, but much more massive; the angle between the longitudinal axis and the axis connecting the anterior and posterior inferior processes is oblique as in *Diplodocus.* The coracoid resembles that of *Diplodocus* in

[10] Charles C. Mook: Notes on *Camarasaurus* Cope. Ann. N. Y. Acad. Sci., vol. xxiv, May 21, 1914, pp. 19-22, 1 fig.

having its anteroposterior diameter much greater than its vertical one; however, it is much larger, and especially much thicker than any known *Diplodocus* coracoid. The ulna is long and relatively slender, though actually stout.

The pubis is very long; it is longer and more slender than that of *Camarasaurus* and larger and more robust than that of *Diplodocus*.

If the inferred characters are correct, *Amphicœlias* has advanced farther in the process of elongation of the fore limbs than *Diplodocus*.

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CHALK, FLINTS, AND GROUND-WATER OF NORTHERN FRANCE[1] [2]

(*Presented before the Society December 27, 1918*)

BY EDWARD M. BURWASH

CONTENTS

The Area studied

During the last four years of war the British military base in France has included practically all the seaports from Calais to Le Havre, and the roughly triangular area between this coast and the part of the front held by them was traversed by their lines of communication and occupied by base depots, training camps, hospitals, rest camps, railway construction troops, and other auxiliary forces to an extent which involved a very large temporary increase in its normal population. It is nearly all underlain by the chalk formation, with the exception of Jurassic areas around Boulogne and to the southwest of Amiens, a Tertiary area which covers the Belgian part of the front and extends nearly as far west as Calais, and another between the Somme and Canche rivers to the north of Amiens. To the south of the line of highlands which runs southeastwardly from Cape Gris Nez the rivers follow a northwesterly course to the sea, and are, in order from north to south, the Liane, which reaches the sea at Boulogne; the Canche (at Étaples), the Authie, the Somme

[1] Entered in the program of the meeting as "Subterranean chalk-streams of northern France."

[2] Revised manuscript received by the Secretary of the Society January 15, 1919.

(at Abbeville), the Brésle (at Le Tréport), and the Béthune (at Dieppe). The Seine forms the southern boundary of the area under consideration from Le Havre to Rouen, after which its margin may be taken as extending eastwardly to the neighborhood of Soissons. The sketch-map which accompanies this article will serve to indicate the proportion of this area which is underlain by the chalk and to give some idea of its drainage system.

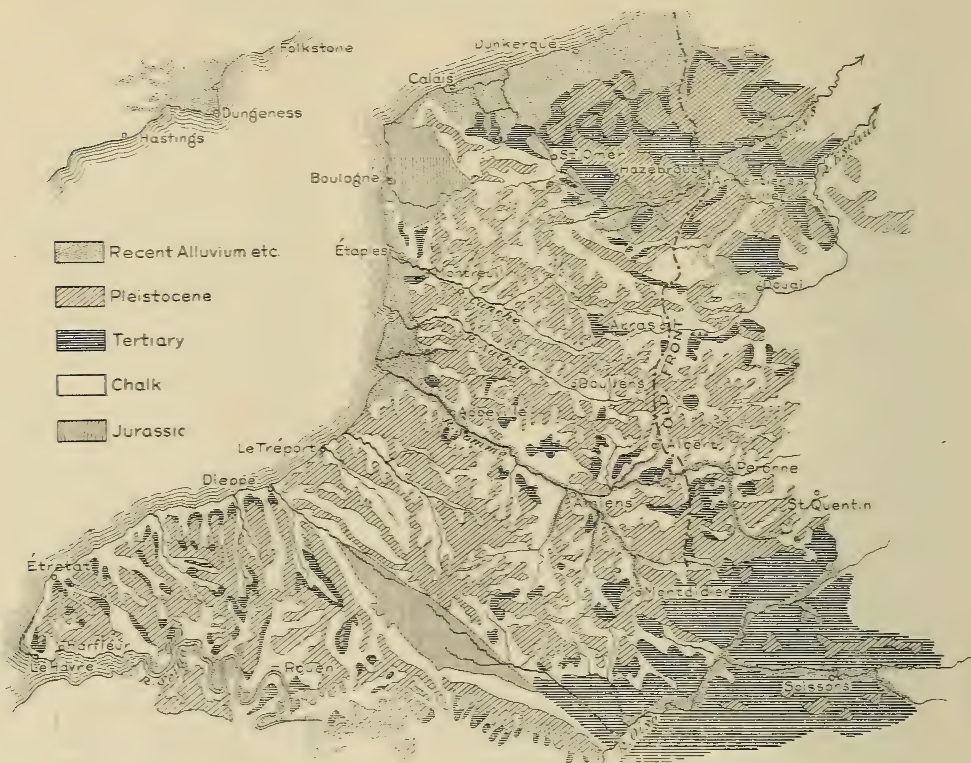

FIGURE 1.—*Map of northern France*
Showing dissection of the "chalk formations."

The Rivers of the Region and their Action

The main rivers occupy mature valleys floored with alluvium during the greater part of their courses, and the interstream uplands, in most cases, have level tops, where they are at all extensive, with easily flowing weather curves on their sides, due to the softness and solubility of the underlying chalk. These flowing curves are, however, often interrupted

by a series of scarps, to be described later. The covering of soil over the chalk of the uplands is in general only a few feet in depth, except where it consists of the wind-blown sands of the coastal belt or, in exceptional localities, of Tertiary and other thicker deposits. The chalk itself has afforded easy passage to percolating waters from a time early in its history. Possibly due to shrinkage in the process of hardening after deposition, it is traversed in all directions by numerous joints, which with well-marked bedding planes divide it into blocks which are seldom of large size. The writer does not remember seeing a block equal to a two-foot cube at any time, and joint blocks of less than a foot in dimensions are much the most usual. While the chalk itself is very absorptive, being capable of retaining water up to about 30 per cent of its bulk when dry, it holds this water very tenaciously and is not easily permeable except along bedding planes and other fissures. Along these numerous crevices ground-waters charged with silica in solution found their way, probably while the formation was still submerged in the sea, when bedding planes and probably joints had already been formed, certainly before it had been elevated to its present position or dissected by erosion, and while still below the ground-water level. The silica was likely derived from the surface material (including chalk) removed during the first cycle of erosion following emergence, or even later, or possibly from ground-waters under "head" which entered the chalk from underlying sands or percolated through it from parts exposed on shore before complete emergence. J. Smith Flett[3] holds that the origin of the silica was siliceous organisms deposited with the chalk, which were dissolved within the substance of the chalk (how, he does not say) and filtered through the "porous medium" to the fissures, where changed conditions caused the precipitation of the silica. He describes the process as "metasomatic" and also as "concretionary" and posits a long time for its accomplishment. This theory of the origin of the silica is based on the ascertained presence of siliceous sponge spicules in the flints and on the facts that some fossil sponges occur, and that the large flints called potstones are often shaped like a species of gigantic sponge, *Spongia patera,* now living in the seas of Sumatra. The presence of diatoms is also thought probable. The flints can only rarely be shown to be fossil sponges, and if they were must have involved the addition of much more silica to the original skeleton. Moreover, the fissures, and not the presence of dead sponges, etcetera, determine the location of flints. They in general show no organic structure, whereas the calcareous shells replaced by flint are recognizable in detail. The presence of undissolved spicules may be also regarded as

[3] See Flint, Encyclopedia Britannica, eleventh edition.

evidence against the supposition of the solution of large quantities of them in the chalk and their redeposition as chalcedony. They consist of colloidal silica, which is not readily soluble in the presence of electrolytes such as dissolved chalk, salt from sea-water, and the products of their reaction ($2NaCl + CaCO_3 \times Na_2CO_3 + CaCl_2$). Insoluble silica, on the other hand, as well as silicates such as clay, are rendered soluble by the presence of Na_2CO_3, and may be redeposited as colloidal silicic acid by treatment with HCl, which is probably present in the fissures, as shown elsewhere in this paper. This colloidal silica as it dries changes slowly back to insoluble silica, and if we suppose this process to have proceeded slowly to partial completion, giving time for crystallization of the silica, the chalcedonic condition of the flints, formed partly of fibrous crystals and to a less extent of colloidal silica, is satisfactorily explained. This also explains the presence in flints of small quantities of alumina, magnesia, and iron and the slight dolomitization of the included chalk.

These circulating waters were, therefore, undoubtedly responsible for the deposition of the flint nodules which occur so abundantly along the bedding planes and also between them, but almost invariably along the joints or other fissures, so far as the writer's observation goes and as English authorities agree.

Theory of Formation of Flint Nodules

The theory has been held that these flint nodules were due to concretionary or gravitational aggregation of siliceous sponge spicules, radiolarian tests, or other siliceous matters deposited at the same time as the chalk or alternately with it;[4] but this theory seems quite doubtful for several reasons:

(1) The platelike and roughly cylindrical shapes of many flints show that they have been deposited in enlarged joint cracks or in passages worn by solution along the line of intersection of two joints or joint and bedding planes. Some tabular forms assume the dimensions of veins. More irregular shapes are often referable to the formation of chambers by solution where a close congeries of cracks has comminuted the chalk and rendered solution more rapid. The cylindrical flints referred to are those which are popularly known as "fossil bones."[5] Like other flints, they are occasionally hollow, and this suggests that they are formed by the filling of a previously formed cavity rather than the usual radial growth of concretions by crystallization which originates round a central

[4] A view held by Buckland and Lyell. See Lyell's "Elements of Geology," page 321 *et seq.*, for a combination of depositional and concretionary hypotheses, and also as to source of silica and origin of potstones.

[5] As to forms of flints and relation to fissures, see article by J. Smith Flett, entitled "Flint," Encyclopedia Britannica, eleventh edition.

nucleus. While the process was probably metasomatic in the sense that the solution of the chalk involved the deposition of the silica, it does not necessarily follow that the deposition of the silica in any given flint was the result of the solution of the very chalk which that flint replaced. The fact that such crystallization as has taken place in the flint appears to have been subsequent to its coagulation as colloidal silica militates against the idea that the silica was drawn from the surrounding chalk by crystalline attraction and that the cavity was formed by the pressure of crystal growth. The transition from flint to chalk in the outer part of the flints appears much like the result of an absorption of the siliceous solution from the cavity into its walls and is certainly not due to the extension of crystal fibers through the chalk.

(2) The fossil sea-urchins which occur in the chalk, and were, of course, originally composed of calcium carbonate, are now for the most part replaced by flint, though some are still calcareous. The silicified examples are sometimes free, but often embedded in other flints, of which, however, they do not seem to have been the original nuclei. This seems to prove that the silicification of the fossils took place much later than the original deposition and subsequent to the formation of joints, bedding planes, and other cracks, and was a part of the process which produced the other flint nodules, tabulæ, and veins.

The silicification of the fossils does not seem to have been a slow process of molecular replacement, since the details of the shells are only roughly preserved. This would point to replacement by deposition from moving waters by a more rapid process. As many sea-urchins while silicified on the surface remain chalky in the center, it seems clear that their silicification was accomplished by material supplied from outside, applied by percolation of solutions along the plane separating their tests from the surrounding chalk. It is believed that these solutions reached the surface of the fossils from cracks in the rock which were situated close to their surfaces, and this would account for the silicification of some fossils and not of others. It would apply to sponges also. The idea that these acted as concretionary centers in the ordinary sense seems to have little foundation as regards the majority of flints. Acids produced by the decay of animal tissues may well have played a part in the deposition while being circulated through the fissures, as well as in the immediate vicinity of the remains, by assisting in the production of hydrochloric acid.

Source of the Silica

The source from which the flint depositing waters obtained their silica can hardly have been siliceous spicules or tests deposited with the chalk,

since the chalk is itself much the more soluble; and in fact the deposition of the flint was probably due in part to the fact that the silica-laden water had reached supersaturation on coming into contact with the more soluble chalk, when the least soluble of the solutes would be deposited as colloidal silica and its coagulation aided by the sodium carbonate. The writer ventures this as a suggestion in face of a considerable weight of authority for a concretionary theory by which siliceous tests and spicules in the chalk are thought to be the source of the silica. This seems to the writer to fail in accounting for the removal of the dissolved chalk which was metasomatically replaced by the silica. If the silica came out of the joint-blocks of chalk, the replaced chalk must have penetrated into them or been carried off through the fissures by moving waters. Such an exchange of molecules between points separated by some distances as the first hypothesis supposes must be made to depend entirely on the forces of diffusion and molecular segregation acting in a substance which was already compact and solid enough to support crevices under considerable pressure of superincumbent rock. The waters through which these forces could act must have been stationary and the theory does not account for the presence of organic matter in the flint. On the other hand, it is easy to suppose that meteoric waters percolating through fissures might introduce organic matter into them and would also be charged with enough carbon dioxide to render the chalk easily soluble. If carbonic acid were wanting, its production might easily be accounted for by the presence of other acids along with the silica, especially in the presence of sodium chloride, with which the chalk must have been charged at the time of its deposition. A small amount of hydrosulphuric or sulphuric acid would be sufficient, while the presence of humous acids must be posited. The reaction would then be

$$H_2S + 2NaCl = 2HCl + Na_2S$$
$$2HCl + CaCO_3 = CaCl_2 + H_2CO_3$$

or perhaps more directly

$$H_2S + CaCO_3 = H_2CO_3 + CaS.$$

Ground-water

This discussion as to the origin of the flints may serve a further purpose, in view of the conditions which undoubtedly prevail at present as to the passage of meteoric waters through the fissures of the chalk, which takes place with great freedom, and also in view of the presence of carbon dioxide, which is commonly found in tunnels and other excavations.

The connection between the existence of fissures and the formation of flints is further rendered clear by the fact that the middle and lower chalk, which consists mainly of much more compact, often sandy, glauconitic, or marly beds, has fewer or no flints, though it contains phosphatic concretionary nodules.

Owing to the free passage which the formation offers to rainfall, the ground-water level in the chalk hills is very low, often little if at all above the neighboring valleys. The writer was familiar with one village well on an upland which was 67 meters in depth. For the same reason tunneling through the chalk hills presents very little difficulty in the matter of drainage, though the presence of the gas already mentioned is sometimes troublesome and the abundance of joints and cracks renders the roof somewhat unsafe and timbering necessary in the Upper Chalk. On account of the extensive tunneling operations carried out during the war, this item of expense must have been a large one. The softness of the rock, on the other hand, facilitates such work to an extent which probably more than counterbalances this expense as compared with rocks strong enough to require no timbering.

Underground Streams

Another phenomenon due to the permeability and solubility of the chalk consists in well defined dry valleys which intersect the chalk hills. Some of these open on the sea and others upon the valleys of the larger rivers. Their general plan and pattern is that of valleys of erosional

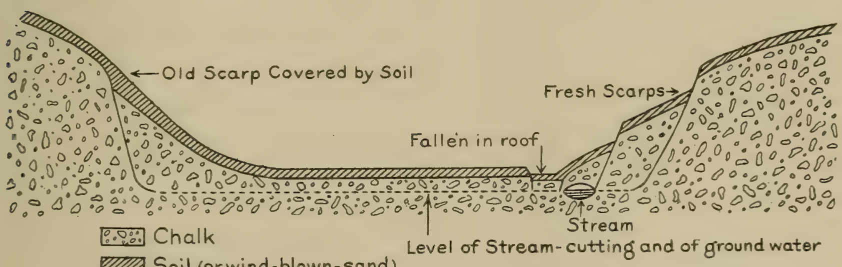

FIGURE 2.—*Diagrammatic Section of Chalk Valley and subterranean Stream*

and not structural origin. They have in general flat floors, at least in the lower part of their courses, and the plan of the valley presents the usual sinuous shapes, with branching tributaries common to stream-cut valleys, a difference being that their heads are rounded depressions in the chalk uplands rather than V-shaped ravines. While destitute of surface streams, their floors are marked by oblong "graben"-like depressions

whose longest axes are in general parallel with the valley, and which may well be formed by the falling in of the roofs of open subterranean channels or caverns. The sloping valley walls are frequently interrupted by scarps, which also run parallel to the valley and of which there may be two or more, one above the other, on the slope, obviously indicating a slipping down of masses of chalk toward the valley bottom. Wells sunk near or in line with the graben encounter a strong flow of water at shallow depths, and the water supply of many of the towns of this region is drawn from what appear to be subterranean streams. The water is in general of very good quality, though "hard," owing to its filtration through the chalk. At Étaples, before the war, a pumping station in a valley only a few miles in length had furnished the water supply for Étaples, Le Touquet, and Paris Plage, with a total population of six or eight thousand. On the establishment of large base and hospital camps in the neighborhood, this supply was found sufficient for more than ten times as many people, with some enlargement of the pumping plant.

Development of the Valleys

The question of the development of these valleys has some features of interest. At Étretat such a valley debouches at the coast, flanked by chalk cliffs on either side. At low water the stream can be seen emerging and flowing into the sea through the flint-pebbled beach at a point under the cliff on the south side of the valley mouth. This is not a mere diffused seepage, but a rapid flow, definitely limited laterally, with a width of about twenty feet. Farther up the valley it appears to be toward the northern side, under the valley floor, where the pumping station is situated. The stream near Étaples also meanders across its valley, as evidenced by the depressions already described, which are found on opposite sides of the valley at intervals along its length and may be as stated formed by the falling in of parts of the roof of the subterranean channel. The scarps seem sometimes to be so placed as to leave the impression that they have been caused by the cutting of a subterranean meander, which may extend, as above described, under the bank, and tends to travel in a down-stream direction much as do those of surface streams.

The surface run-off carries the soil overlying the chalk down the sides of the valley and spreads it over the valley floor. This deposit is thickest near the lower end of the valley, and here a small surface stream may be formed which flows entirely over this alluvium and is quite distinct from the main stream beneath.

In a country where intensive cultivation pollutes the surface streams, the presence of these subterranean supplies of chalk-filtered water is in-

deed a fortunate circumstance, especially under such conditions as those of the late war.

The writer's theory as to the history of such streams is that in the early stages of the development of the present drainage system their location was determined, like that of other surface streams (as they then were), by the general slope of the country and irregularities of surface due to slight folding during uplift, and other causes.

The streams, having cut through the superficial soil or drift, would continue to deepen their valleys through the chalk in the ordinary way unless the ground-water level in the chalk were much below the bottoms of the streams. If such were the case, there is no doubt that the smaller streams would be absorbed by seepage through the chalk and descend until they encountered the surface of the water-table beneath. Experimental demonstration of this contention was furnished during the war by the efficiency of sumps cut into the chalk in disposing of surface drainage of camps, trenches, etcetera, by seepage. Having reached the surface of the water-table, the stream would no doubt tend somewhat to coalesce with it and spread out over it; but, the descending volume here being much greater than the seepage from the surrounding country (from the surface run-off of which the stream is formed), the surface of the water-table along the locus of the stream would tend to be kept at a higher level than on either side. The water-table dips toward the outlet of the surface streams; hence the waters of this elevated ridge or mound, especially at its downstream end, in seeking their level would flow much more quickly and exercise their solvent power more rapidly along the line of that dip than in other directions—that is, the main movement would be parallel to the original flow of the surface stream. As the fissures were more rapidly enlarged along this axis, they would afford the easiest outlet for an increasingly greater proportion of the descending volume until an open channel was formed sufficient to accommodate most of it. As this channel deepens by erosion of its floor the surface of the water in it would sink until, like that of a surface stream, it became the lowest part of the surrounding water-table, and the relations of the underground stream to the water-table on either side would be similar also in other respects to those of ordinary streams. The motion of ground-water would now be toward the stream and downstream, instead of away from the stream axis and downstream. The foregoing argument is based on the assumption that the fissuring of the chalk permits the passage of water with equal facility in all directions, and this seems borne out by facts of observation.

As the ground-water surface would be lowest near the seacoast or the

valley to which the stream was tributary, the disappearance of the stream from the surface would commence in the lowest part of its course. Once established here, the underground channel would be extended headward by the rapid flow of water into its head so long as the stream continued to be absorbed by the fissures of the chalk. This would in turn lower the ground-water level farther upstream and establish the conditions already described.

Relations of the Streams to the Water-table

The relations of streams which flow over the chalk to the water-table is indeed somewhat exceptional, since they are said seldom to flood, owing to the ready absorption of the surplus surface run-off into the water-table on either side of the stream through the interstices of the chalk.

When the stream had got down to grade throughout its course, the process of deepening the dry valley above it by gradual sinking in of the roof of the channel and its removal by solution would continue until possibly the whole of it would be removed and the stream appear on the surface again. No case of this sort was observed by the writer, however, but parallel instances will easily suggest themselves from other limestone regions.

The tendency to meander probably depends generally on the same causes in an underground as in a surface stream, but the possibility of diversion by heavy falls of the roof must also be taken into consideration. In either case the meandering would result in the removal of a horizontal layer, producing a flat-bottomed valley, and in either case this maturity would begin in the lower part of the stream's course and extend upstream. Meandering is probably more pronounced in chalk than in harder limestones, and for this reason complete unroofing may be rarer in the chalk.

The rapid formation and recession of sea-cliffs through wave-action may have caused the adoption of a subterranean course by some streams by rapid lowering of the water-table near the coast. Instances were observed of wells near the coast which in recent years have gone dry from this cause. The larger streams would deepen their valleys fast enough to keep pace with the uplift of the land, thus lowering the ground-water level in adjacent uplands and compelling their tributaries of less erosional power to disappear beneath the surface, following the sinking water-table.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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MILITARY CONTRIBUTION OF CIVILIAN ENGINEERS[1]

BY GEORGE OTIS SMITH

(Read before the Society December 27, 1918)

CONTENTS

Introduction

The original distinction between military and civil engineering has gradually lost its force, in no small measure because of the practical interchange of military and civil engineers on governmental works that are wholly civil in nature. The record of the graduates of West Point in river and harbor improvement, culminating perhaps in the construction of the Panama Canal, is evidence of this tendency. In recent months, however, any line of separation between civil and military engineers has been wholly lost sight of by reason of the military contribution of civilian engineers to the military program, which has been so largely an engineering program. How great and varied that contribution has been will doubtless be set forth in some presidential address before one of the great engineering societies, yet this meeting of the Geological Society of America is an opportune time for mention of one phase of this progress of engineering.

Growth of Civil Engineering

The growth of civil engineering during the last century has followed the description of the objects of this profession given by Tredgold in 1828: "The real extent to which it may be applied is limited only by the

[1] Manuscript received by the Secretary of the Society December 28, 1918.

progress of science; its scope and utility will be increased with every discovery in philosophy, and its resources with every invention in mechanical or chemical art, since its bounds are unlimited, and equally so must be the researches of its professors." Thus is to be explained the great variety of engineers included in the large membership of the half score national engineering societies. Even in the civil service of the Government, in the scientific bureaus and industrial commissions at Washington, there are many varieties: electrical engineers as well as sanitary engineers, construction engineers and topographic engineers, testing engineers and mining engineers, chemical engineers and hydraulic engineers, geologic engineers and naval engineers. The membership of the Washington Society of Engineers on a peace basis therefore showed a proportion of about 38 civilian engineers to one military engineer.

Cooperation with Army in topographic Surveys

The active cooperation of the United States Geological Survey with the United States Army in topographic mapping was formally expressed in an agreement under date of October 11, 1911, drawn up by Colonel Boughton, representing the War College, and the Director of the Survey and approved by Secretary of War Oliver and Secretary of the Interior Fisher. The collection of military information and the mapping of selected areas under this arrangement brought the field men of the Survey into closer touch with the military needs of the Government. Early in 1914 the army authorities made an informal request that the Geological Survey should hold its topographic engineers in readiness for special service under direction of the War Department, and even after the crisis of that date passed the Survey's field assignments in part were made with regard to availability in time of need. There was also formal recognition in the interdepartment correspondence of this fact that a civil branch of the Government engineering service could be regarded as a reserve corps, even in the absence of any specific legislative authority.

The Brooks Memorandum on Reserve Corps

The continued discussion with the officers of the Army War College concerning topographic work, however, led to the transmittal in May, 1915, of a memorandum on the subject of a reserve corps made up of professional men in civil service. This memorandum was prepared by Alfred H. Brooks, then the Chief of the Alaskan Division of the Geological Survey and now Lieutenant Colonel of Engineers and Chief Geologist of

the American Expeditionary Force. As I then remarked to General Macomb, President of the War College, Mr. Brooks not only spoke from a ripe experience in administering scientific fieldwork, but as the son of a volunteer officer in the Civil War he had a pride in the military efficiency of the United States and a desire to see the civil service cooperate with the army.

In his memorandum Mr. Brooks suggested the organization of a reserve corps of engineers and quartermasters corresponding to the medical reserve corps of the War Department. That the suggestion was both opportune and meritorious was indicated in a letter from General Macomb, who on June 5, 1915, wrote to me that the letter transmitting the "plan for a reserve corps of professional men has been the subject of study here for the past week, and I believe the idea is going to have a much wider application than Mr. Brooks indicated." While General Macomb was not at liberty to state the details of recommendations to the chief of staff, he continued: "I can assure you that we are all interested in the idea and see great possibilities in the plan as it has been developed."

A few extracts from Mr. Brook's memorandum will serve to outline his plan for a reserve corps so far as it related to the engineers:

"Many of the Government scientific and technical bureaus include in their membership a large number of highly trained professional men whose special knowledge might be of great value in time of war. It is proposed that these should be organized into a reserve corps to supplement, in case of need, the officers of the regular army. . . . There are over 500 engineers in the Interior Department alone and probably over 1,000 in the classified civil service. There should be no difficulty in selecting from these several hundred men who would, with some training, be well qualified in case of need to supplement the Engineer Corps of the Army. . . . In case of emergency they could be used to fill the subordinate positions and would be available at any time at short notice, for their telegraphic addresses would be a matter of record in the various bureaus.

"The plan here proposed of forming reserve corps of engineers and quartermasters involves the giving of some special instruction to the men chosen. For this purpose authority would have to be asked, but as practically no additional expenditures would be involved it would probably not be difficult to obtain the necessary legislation. It appears that what would be required is (1) authority for creating such reserve corps from among the professional men in the civil service; (2) authority to have such men detailed for a certain period each year for special instructions. . . .

"While the above plan necessitates legislation before it is put into effect, it would be possible to make a start without congressional action. The proposal is to obtain a complete roster of the professional men in the civil service whose special training might be of value in time of war. This would require only an expenditure for printing and clerical work."

Secretary Lane's Offer

In April, 1916, Secretary Lane submitted to the Secretary of War an outline of the services that could be rendered by the engineers in the Department of the Interior. This statement included mention of the geologists, topographers, hydraulic engineers, and chemists available for immediate service and emphasized the intimate knowledge of the United States possessed by the members of the field force, from whom could be selected men who knew by experience every line and kind of transportation for most areas in this country. Emphasis was placed upon the fact that the wide distribution of the field force during the summer would add to their availability in an emergency, in that some engineers would probably be within striking distance of any place in the United States where their services were needed and if previously enrolled in a reserve corps could at any time be placed under orders of the War Department by telegraph and could report wherever needed without delay.

The National Defense Act of June 3, 1916, authorized the organization of a corps of reserve officers not only for arms of the line, but also for various staff corps and departments, and the War Department, in a memorandum dated October 21, discussed several steps that could be taken under this act by the scientific and engineering members of the Interior Department. The War Department mentioned first the "exceedingly valuable aid" it had received for a number of years past in the preparation of the military map and requested the continuation of this cooperation; also aid in the collection of military information. Regarding the Officers' Reserve Corps, it made the statement that field men with "scientific training in certain lines would probably make very efficient officers of the Engineer, Ordnance, or Quartermaster section of this reserve." The Secretary of War mentioned, however, the obvious fact that many of the functions of the Interior Department should not be interrupted by war, so that only those members whose services could be spared to the War Department at the outbreak of the war should be commissioned in the reserve corps; hence the requirement of the approval of the Secretary of the Interior of any application for commission.

Action under National Defense Act

The first action in the Department of the Interior under this reserve corps legislation was taken in January, 1917, when 90 topographic engineers of the Geological Survey, with the approval of the Secretary of the Interior, applied for commissions in the Engineer Officers' Reserve Corps.

On March 26, 1917, a program for military mapping in the United States, drawn up by the General Staff of the Army, was submitted to the Geological Survey; three days later the fieldwork requested was under way, and within the week fifteen topographers were at work in three States, followed by a large number in the first few days of April. These facts are mentioned as evidence that the reserve engineer officers were in fact available to meet the call for special service without delay. The utilization of this civilian organization for the highly specialized service of military mapping in the United States has continued since March, 1917, and at the end of November, 1918, the area covered, both under the original program and under subsequent requests by the Chief of Engineers, amounted to nearly 35,000 square miles, 624 square miles of which have been mapped on exceptionally large scales and the remainder on the scale of 1:62,500. The work comprised under special requests has included mapping of areas involving great detail, such as balloon fields, cantonment sites, and artillery proving grounds. The force employed has included civilian members of the United States Geological Survey as well as engineer officers detailed to the Director of the Geological Survey for this purpose, and the whole project of military mapping in the United States has served a double function, furnishing the maps required by the army and training engineer officers and assistants for service overseas.

Not to mention all the other contributions of the many technical organizations, both private and connected with the Government, the military contribution overseas of this one scientific bureau may be briefly stated. On November 11, 1918, sixty-six topographic engineers from the United States Geological Survey were serving as engineer officers in the American Expeditionary Forces; Lieutenant Colonel Brooks and three other geologists from the Survey were serving as geologists and three other members of the Survey staff had been selected for geologic work in France and were awaiting embarkation orders; another *per diem* member of the Survey was in France on important staff duty; and still another of the Survey engineer officers was engaged in railroad construction in France, while scores of the younger men trained as field assistants were performing similar service with the surveying regiments officered by the engineer officers from the United States Geological Survey.

John Duer Irving's Service

The spirit that made most effective all this service of the civilian engineer to his country has nowhere been better exemplified than in the contribution of one American geologist, John Duer Irving, a former associate

of many of us, who left his university work to devote every activity of his well trained mind to his country's need. He proved with his life that the civilian engineer was ready to render military service of high engineering quality.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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MILITARY AND GEOLOGIC MAPPING—A PLANE-TABLE [1]

BY ALAN M. BATEMAN

(*Presented by title before the Society December 28, 1918*)

CONTENTS

INTRODUCTION

In most branches of the army a knowledge of map reading and mapping methods is necessary, and in the artillery it is essential. Not only must the artillery officer be conversant with the interpretation of maps, military and topographic, but he must have knowledge and skill in making sketches and in locating positions by traverses, intersection, and resection. Much of this work is of a reconnaissance nature, with a considerable allowable error, but where it involves the locating of batteries and battery commander stations for use upon firing maps, the locations must be accurately made. These locations are preferably made by intersection, simple resection, or by Italian resection[2] or other three-point methods which give a high degree of accuracy. For all such purposes the plane-

[1] Manuscript received by the Secretary of the Society February 7, 1919.

[2] Italian resection is one of the three-point methods of accurately locating a position and orientating a map when three points on the map can be seen on the ground. It was adapted by the Italian Army from Bassell's method; hence its name. It was later adopted by the French and American armies as the authorized method for locating positions where accuracy is required.

table is the most satisfactory instrument and the geologist is particularly adapted to render such instruction.

For the purpose of instructing artillery students and officer candidates of the Reserve Officers' Training Camp and members of the Students' Auxiliary Training Camp at Yale University in these phases of the work, a simple plane-table equipment and methods were used, which, for the instruction of large numbers, yielded more accurate and efficient results than the methods generally employed throughout the training camps of the country.

These features are here presented in the hope that they may be of use in future military training, and particularly that they may be of value for the training and use of geologists in their fieldwork.

Equipment

COST

The plane-table and the alidade were designed for simplicity and cheapness, the materials being obtained and made locally at a total cost of $1.53 each for a lot of 160. A single outfit could be obtained from a country village in a few hours, and thus be available for a field geologist needing one on short notice. For instructional purposes their cheapness allows large numbers to be obtained at a small cost, thus enabling better individual instruction to be given.

PLANE-TABLE

The tripod is an ordinary, cheap, wooden camera tripod with sliding legs in two parts (see figure 1). The legs are permanently fastened to the head, insuring greater stability than with those types which are detached from the head. The sliding legs shown in figure 1 also tend toward greater stability than those which are taken down by folding back on themselves, as in the more expensive type of camera tripods. While they are not as stable as solid legs, they have the advantage of lightness and of being shortened to one-half their total length.

The camera tripod is often objected to because of its instability, and it is true that many types are too unsteady for plane-table work. However, the one described here was found in practice to be so steady that points could be accurately located by the precise three-point methods.

The board is of pine, 15 inches square, with inset ends to prevent warping. A brass nut inserted in the lower side enables the board to be screwed to the tripod head, and the same screw is used to clamp or unclamp the board.

ALIDADE

The alidade customarily used for this work is the triangular wooden ruler, either weighted or unweighted. While a fair degree of accuracy may be obtained on level ground with this type, it is unsatisfactory, because sights to objects above or below the level of the table are inaccurate

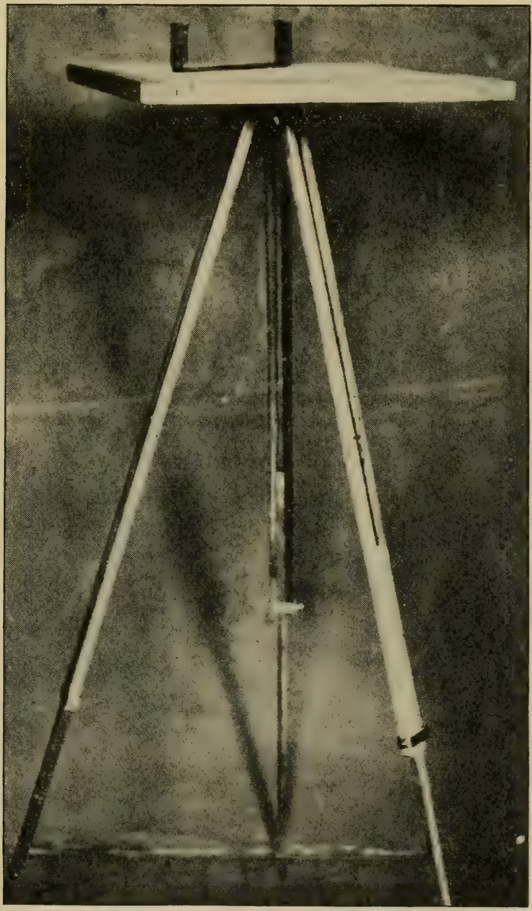

FIGURE 1.—*Light Plane-table with Camera Tripod*

or impossible, and even horizontal sights are susceptible of being inaccurately taken unless considerable care is exercised. A simple and cheap alidade was designed to replace the triangular ruler, consisting of a bar of steel with the ends bent upward for arms and each arm slotted (see figure 2).

It is 9 inches long, ¾ of an inch wide, and 3/16 of an inch thick, with two-inch arms at either end. This height of arm gives an accurate sight through a vertical angle of about 12 degrees, and by extending the line of sight upward from the slots a sight almost as accurate may be obtained through twice that vertical angle. The slots are about 1/30 of an inch wide, giving a fine line of sight. One side of the alidade should be left rough, so that the smooth side only can be used, thereby eliminating any error that might arise from using two sides, if the slots should not be accurately centered.

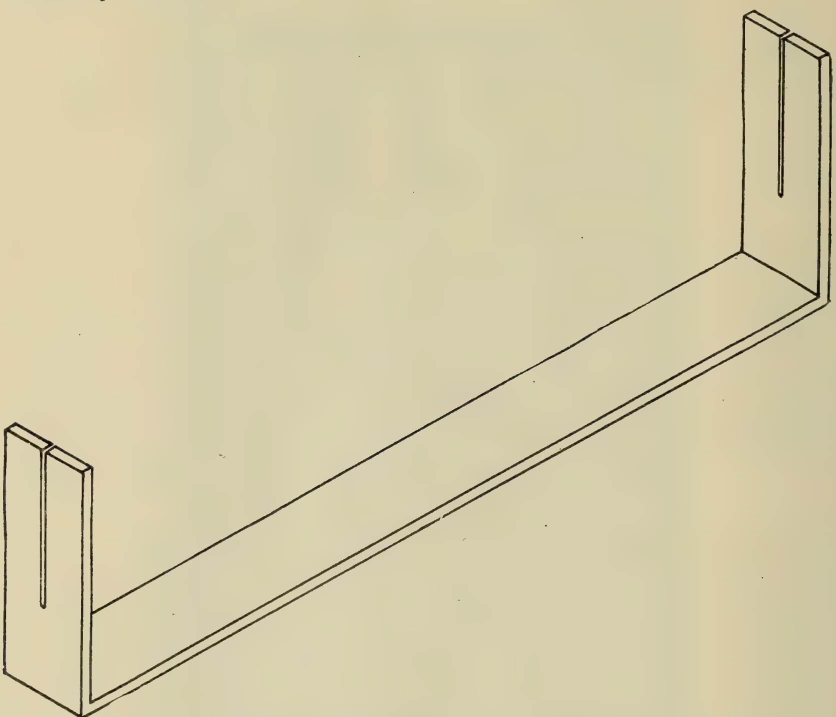

FIGURE 2.—*Steel Alidade with fixed Arms and saw-cut Slots*

COMPASS

No trough compass is inset into the board. An ordinary pocket compass laid on a north line on the paper proved entirely satisfactory.

SLOPE CARD

The usual type of slope board advocated in the text-books on military mapping, consisting of a long string with a weight on the end of it, attached to the back of the board, was found in practice to be entirely un-

satisfactory. It was cumbersome, difficult to read, and only very approximately accurate. To replace this, a "slope-card" was designed by adding somewhat to the arm protractor and goniometer patented by the late Professor Penfield and used for measuring crystals (see figure 3). It consists of a rectangular, heavy, stiff cardboard, 6 3¼ inches wide, containing a 180-degree scale, numbered from both ends, with additional centimeter and inch scales for convenience. A movable celluloid arm, A, pivots at the middle of the diameter of the semicircle C, equivalent to the index point of any protractor. A pendulum, D, swings freely from

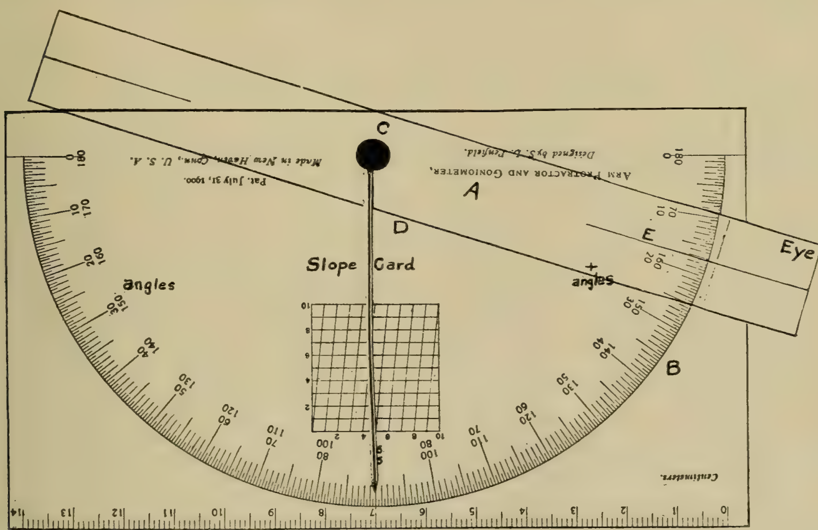

FIGURE 3.—*"Slope Card" to replace slope Board*

Adapted from arm goniometer designed by S. L. Penfield. A is movable celluloid arm pivoting at C, along top of which sight is taken. Reading is taken where line E intersects graduated scale. B is a double protractor scale graduated to 180 degrees, with zero at the top on both sides. A freely swinging pendulum, D, pivots at C.

the same index point. It is merely a piece of stiff steel wire with the index end pointed and the other end bent into a loop which allows it to be suspended as a pendulum in the hole at C.

In use the card is held with its longer edge firmly on the plane-table, with the round part of the semicircle downward. The table is adjusted until the swinging pendulum points to 90 degrees, or the center of the protractor, thereby indicating that it is level. The object is then sighted along the blackened edge of the movable celluloid arm A, shown in figure 3, and the angle of slope read directly by means of the scratched line E, on the under side of the arm. Positive angles are recorded on one side

and negative on the other. Slopes may thus be read to one-quarter of a degree.

The advantages of this slope-card over the slope-board are: Its greater reading accuracy; the fineness of the line of sight, due to its stability on the plane-table; greater speed of work; it is unaffected by wind; and the operation of sighting and determining the angle of slope is independent, whereas in reading by a swinging pendulum one is forced to determine the reading while the line of sight is being made; also, the whole instrument is detached from the sketching board itself, thus allowing several slopes to be read without having to change the position of the table. The slope-card may also be used for simply leveling the board when considerable accuracy is needed for intersections, and with careful manipulation an error of a quarter of a degree need not be exceeded.

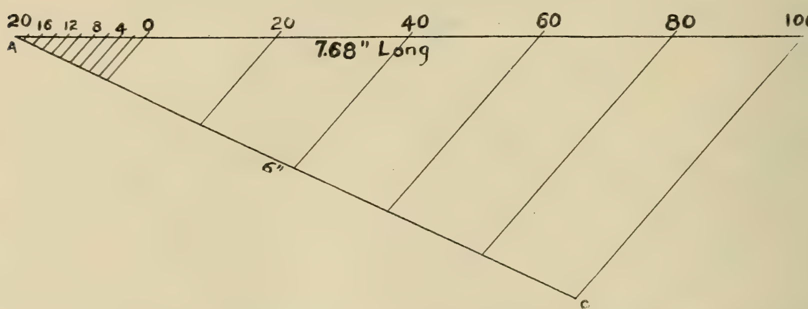

FIGURE 4.—*Method of dividing a Line of irregular Length into a given Number of equal Parts to obtain proper Units of Strides*

The angle B A C is assumed; A C is of any length which is readily divisible into the desired number of units. B C are joined, and the other points projected by lines parallel to B C.

SCALES

Pace scales of 1/1000, 1/2000, 1/2500, and 1/5000 were made for each individual stride. Scales based on miles per inch instead of the metric system might also be used if desired. The scale problem was first made on a sheet of paper and the measurements then transferred directly on the wood of an 8-inch triangular ruler. Each scale can be used as a smaller or larger scale by adding or dropping a digit to each division. An example of a scale construction follows:

Construct a scale of 1/1000 for a man whose stride is determined to be 64 inches; scale to read 120 strides, divided into units of 20 strides, with left-hand division divided into units of 2 strides.

To do this, note that—

1 inch on scale = 1,000 inches on ground = 15.62 strides; therefore,

120 strides = 7.68 inches.

Then divide a line 7.68 inches long into 6 equal parts of 20 strides each, by proportion, assuming at any angle a line readily divisible, such as 6 inches (see figure 4).

If the left-hand inch of A C be divided into 1/10 of an inch, then one unit on the scale will be divided into divisions of 2 strides each, thus giving a scale on paper which can be transferred to the triangular ruler (see figure 5, A). Similarly, working scales may be constructed for any fraction, whether metric or miles per inch.

Methods

For all plain mapping, such as traversing and location of points by intersections and resections, the equipment described above is used in the same manner as the standard reconnaissance plane-table and folding alidade, except that orientation of the plane-table by back sight is used, wherever possible, in preference to compass orientation, since it insures greater accuracy. The methods for this type of work may be found in almost any text-book on surveying or military mapping.

The results of the work using this equipment were found to be well within the allowable errors, and in locating points by the Italian resection or other three-point methods the accuracy was comparable with that obtained in using the more expensive standard equipment. The allowable error for pacing is usually considered to be 2 per cent; so that if pacing is the method of measurement employed, the error of all the work can not be less than 2 per cent. With the open-sight alidade, however, the degree of accuracy is much greater and locations by intersection will yield closer results, which on a scale of 1/10000 would not exceed the width of a pencil line.

For topographic work the base outline is constructed in the usual manner and elevations are obtained by means of the slope-card and a slope scale combined with the pace scale. Slope angles are read in degrees, by means of the slope-card, to critical points or positions located by triangulation. The distances from the observer to these positions are scaled from the map or paced. With the slope angle and horizontal distance, the vertical distance or difference in elevation can be calculated. The elevations may then be recorded on all measured points, and contours interpolated, thereby giving a topographic sketch map of an area.

Construction and Use of Slope Scale.

When the slope angle and the horizontal distance in strides[3] between any two points are known, the difference in elevation may be read directly by the construction of either a chart or slope scale. The chart may be so made that one axis represents distance in strides, another degrees of slope, and a third the corresponding difference in elevation, measured in feet. The slope scale, however, was found more practical and convenient. It is so constructed that differences of elevation in feet for one degree of slope are read directly opposite the figure on the distance scale representing the horizontal distance between the two points (see figure 5, B). It is constructed as follows:

Problem: Construct a slope scale to be used with a working scale of 1/1000.[4]

This means that 1 inch on the scale equals 1,000 inches on the ground,

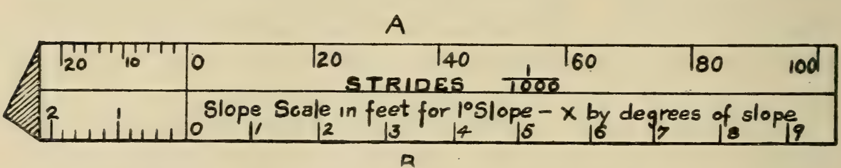

Figure 5.—*Slope Scale (B) on same Ruler as Stride Scale (A)*

The slope scale is so placed as to give difference in elevation in feet, opposite the distance in strides between two points, for any degree of slope.

Now, 1 degree of slope equals 1 foot rise (or depression) in 57.3 feet; equals 10 feet rise in 573 feet, or 6,876 inches, on the ground.

Thus, for 1 degree of slope, 10 feet rise (or depression) would be represented on the scale by 6876/1000, which equals 6.876 inches. By the method of proportion shown in figure 4, divide on paper a line 6.876 inches long into 10 equal parts, each one of which will represent 1 foot rise (or depression) on a scale of 1/1000. This may be called the slope scale. These divisions may then be transferred to the triangular wooden rule, so that the zero of the slope scale is set directly opposite the zero of strides on the working scale (see figure 5, B). The elevation divisions may be extended to the left of the zero, as shown in figure 5, B, and further subdivided to read fractions of feet. Similar elevation scales may be made corresponding to any desired horizontal scale or any desired unit of horizontal measurement. The scale, constructed as described above, will then give the number of feet elevation for a 1-degree slope for any

[3] Any other desired unit of measurement can be employed.

[4] The problem is the same, regardless of what working scale may be used.

horizontal distance in strides[5] by simply taking the number on the slope scale directly opposite the determined horizontal distance.

For slopes greater than 1 degree, multiply the number found on the slope scale by degrees of slope. For example: If the horizontal distance between two points be 80 strides, then for a 1-degree slope between two points the difference in elevation between them is the number directly opposite 80, or approximately 7.5 feet. For a 4-degree slope it is 4 times 7.5, or 30 feet. This direct multiplication, instead of using trigonometric functions, however, produces an error which increases with the size of the angle. By trigonometric calculation the error in the elevation for a 4-degree slope is .027 of a foot, or 0.09 per cent, and only reaches 1 foot, or 1.2 per cent, with an angle of 11 degrees. It may be seen that this is within the allowable error and may be disregarded for the slopes encountered in such work, but correction could be made for it if desired.

In fieldwork or in plotting, the slope scale enables the difference in elevation between any two points to be determined rapidly by simply laying the slope scale between the same two points on the map and reading directly the number of feet of elevation corresponding to the horizontal distance. For example, the horizontal distance between any two stations, A and B, may have been determined by means of either triangulation or pacing and recorded on the map. Then, by placing the slope scale on the map with its zero at Station A, the corresponding elevation for a 1-degree slope may be read directly on the scale opposite Station B.

Conclusions

The equipment mentioned above may be used efficiently for instructional purposes, either military or geologic, and for geologic reconnaissance in the field. Its extremely light weight, only 4⅛ pounds, including the alidade, renders it particularly adapted for reconnaissance work in mountainous regions where climbing is involved and lightness of equipment is an important matter.

In military instruction it is adapted for exercises in traversing, intersection, and resection; positions may be accurately located by means of the Italian resection, and it is especially useful for the various kinds of plain and topographic sketching. The alidade and slope-card allow of accuracy for such work that can not be attained with the equipment ordinarily used and described in the text-books on military mapping.

For instruction in geological field methods, the cheapness of the outfit

[5] The same holds true for any unit of horizontal distance on the scale, whether it be strides, feet, or meters, etc.

and the readiness with which it may be constructed will enable large numbers to be obtained, so that each student may do individual work with an individual plane-table. For teaching students the principles of location, its simplicity is an advantage rather than a disadvantage, as their minds are not distracted from the subject by having to master the numerous screws and adjustments of more refined instruments.

The equipment described here is not intended for extremely accurate work, involving small allowable errors, but for such purposes as reconnaissance sketch maps and geologic mapping with or without a topographic map. To employ precise methods and instruments for work which does not need to be precise, or from its nature is incapable of being made precise, is laborious and a waste of time and money. Most geologic mapping is of this nature, for an outcrop of a bed which is irregular in thickness, strike, and dip can not be located within a few inches and usually not within a few feet. For such work simpler instruments and approximately accurate methods are proper because of the time and expense saved.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 30, PP. 415-422 SEPTEMBER 30, 1919

TOPOGRAPHIC FEATURES OF THE HUDSON VALLEY AND THE QUESTION OF POSTGLACIAL MARINE WATERS IN THE HUDSON-CHAMPLAIN VALLEY[1]

BY JAMES H. STOLLER

(Presented before the Society December 27, 1918)

CONTENTS

Introduction

Different conclusions have been reached by geologists as to the question of the southern extension of the postglacial marine waters that filled the Champlain depression. In the present paper the writer undertakes the discussion of this problem from a new point of attack.

The Change of Course of the Iroquois-Mohawk River

The body of glacial waters which occupied the middle Hudson and lower Mohawk Valley region, known as Lake Albany, received deposits from the Mohawk River during the period when this river was the outlet of the great interior lakes. These deposits formed a great delta heading west of Schenectady and spreading southeastward. With the subsidence of the Lake Albany waters the delta emerged as land surface, forming the great sand plain extending southeastward from Schenectady. The Mohawk currents, impeded by the emerged delta deposits, were diverted northward through the preglacial valley depression known as Ballston Channel and discharged into Lake Albany in the Saratoga-Round Lake region.

[1] Manuscript received by the Secretary of the Society January 25, 1919.

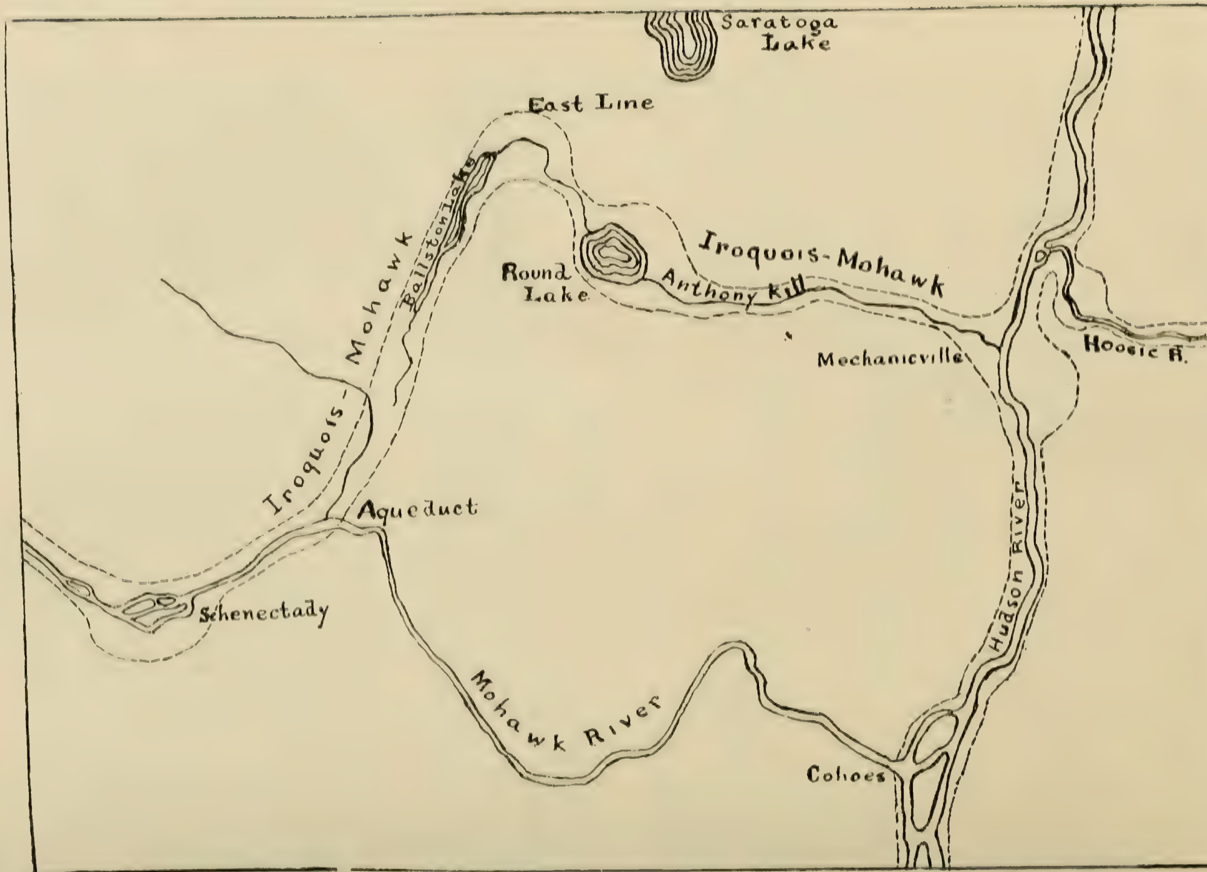

FIGURE 1.—*The Course of the Iroquois-Mohawk River*

This sketch map shows the course of the river at the time when the waters of Lake Albany had subsided to the level of the 100-foot terraces at Mechanicsville. The course and approximately the width of the Iroquois-Mohawk are indicated by broken lines. The width of the shrunken Lake Albany in the Hudson Valley is also indicated by broken lines.

At the same time a portion of the flooded waters escaped over the rock strata bounding the Ballston Channel at Aqueduct, 3 miles below Schenectady. Eventually these currents undercut the northward channel, thus establishing the present postglacial course of the Mohawk from Aqueduct to its place of discharge into the Hudson River below Cohoes.

For a long time, however, the main volume of the Mohawk waters coursed northward through the Ballston Channel. With the further recession of the Lake Albany waters the Mohawk currents developed a valley extending southeasterly from the northern end of the Ballston depression to the Round Lake inlet. At a later stage, with the further subsidence of the lake waters the Mohawk currents eroded out the broad and deep valley, now followed by Anthony Kill, which opens into the Hudson Valley at Mechanicsville.

The above statements are deductions from the present topographic features of the localities referred to, especially the following:

(1) The basin of the Mohawk at Schenectady bounded to the south by a crescentic bluff of the Lake Albany clays marking the course of the Mohawk currents as they cut into the delta deposits and swerved northeastward.

(2) The continuity of the basin with the preglacial rock valley (Ballston Channel) extending northeasterly to the Saratoga-Round Lake region. The bottom of this valley stands at 300-foot elevation, which is 60 feet below the summit of the clay bluff.

(3) The broad and deep rock gorge extending from the Ballston Channel at East Line southeastwardly to the Round Lake depression. There is a fall of 97 feet from Ballston Lake, which lies in the northern portion of the Ballston Channel, to Round Lake, 4 miles to the east.

(4) The broad and deep valley (now followed by a small stream, Anthony Kill) cut in the Lake Albany deposits from Round Lake to the Hudson Valley at Mechanicsville.

The writer may add that this interpretation of the course of the Iroquois-Mohawk during the period of the subsidence of the Lake Albany waters was first described by him in New York State Museum Bulletin Number 154, pages 31-33, and has since been recognized by Professor Fairchild in New York State Museum Bulletin Number 195, page 12. (See also the accompanying sketch map, figure 1.)

The Terraces at Mechanicsville

The main purpose of the present paper is to call attention to the topographic features of the Hudson Valley at Mechanicsville, where the Iro-

quois-Mohawk currents discharged into the Hudson Valley waters, and the deductions therefrom that seem clearly warranted and have a bearing on the question whether the Hudson-Champlain Valley was occupied by a body of sealevel waters connecting the Saint Lawrence arm of the sea with the ocean at New York.

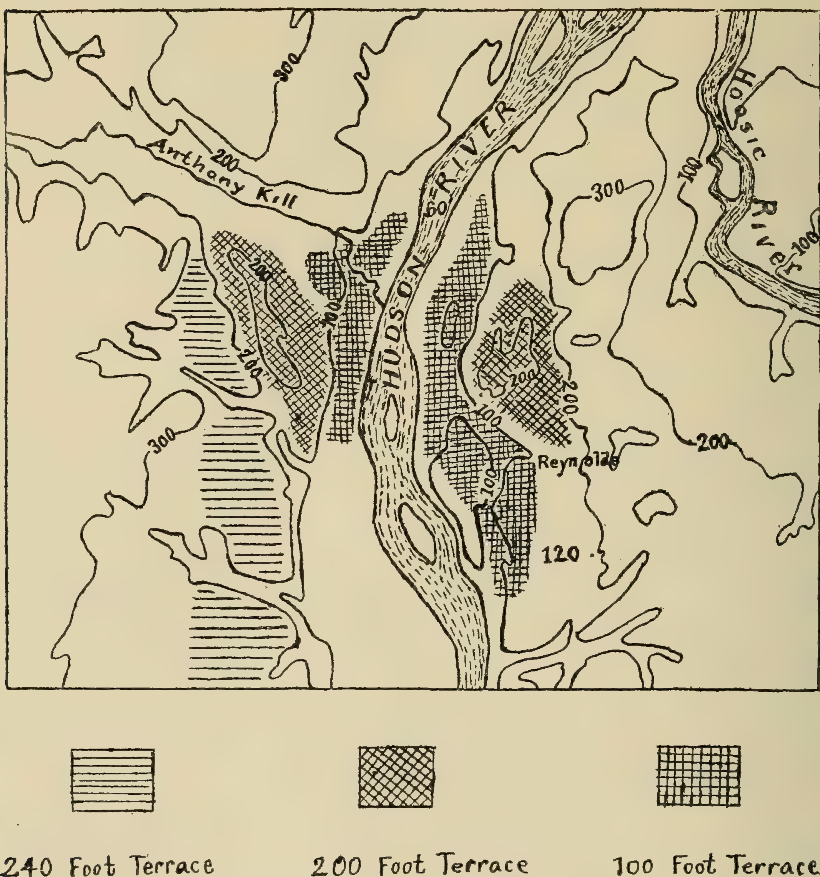

FIGURE 2.—*The Terraces at Mechanicsville*

The 100-foot interval contour lines are drawn from the topographic map (Cohoes Sheet) of the U. S. Geological Survey. On the topographic map the 20-foot interval contour lines, here omitted, show the bluffs separating the several terraces. The city of Mechanicsville is located on the 100-foot terrace west of the river.

At Mechanicsville there are three distinct terraces fronting the Hudson Valley from the west. The uppermost of these is at the 240-foot level and is a part of the well known brick-clay terrace formation developed on

both sides of the Hudson Valley. The terraces of this formation are terraces of deposition, representing the surface of sediments deposited in the middle portion of Lake Albany and converted into terrace form through cutting down by southward flowing currents of the Hudson Valley waters. The 240-foot terrace at Mechanicsville is a segment of the general terrace on the west side of the valley, cut off from its northern extension by the Iroquois-Mohawk Valley above described and from its southern extension by a gully formed by a small stream tributary to the Hudson south of Mechanicsville.

The next lower (or middle) terrace is at the 200-foot level. It is separated from the upper terrace by a bluff 40 feet high, as shown by the contour lines of the sheet. The trend of this bluff shows that it was formed by the cutting down of the inner portion of the area of the upper terrace by strong currents issuing from the western tributary valley—that is, Iroquois-Mohawk currents. This terrace is therefore a terrace of erosion in contradistinction to the upper terrace, which is a terrace of deposition.

On the east side of the valley there is a terrace symmetrical to the one just described in location, elevation, and form relations. This was formed by Iroquois-Mohawk currents sweeping across the waters of the narrowed Lake Albany and impinging against a frontal lobe of the Hoosic River delta, which had been built out into the lake in this quarter at the time when the lake waters were at their height. These currents cut laterally into the materials of the delta, carving out a shelf-like terrace and reducing it by downward cutting to the 200-foot plane.

The third (lowermost) terrace at Mechanicsville stands at the 100-foot level. It is separated from the middle terrace by a bluff 80 feet in height. The trend of this bluff northwesterly shows that it was formed by the cutting action of currents flowing in from the western tributary valley. This terrace also has its companion on the opposite side of the Hudson with quite definite outlines. The striking bluff extending northwesterly from Reynolds and forming the outer margin of the 100-foot terrace was quite evidently formed by currents issuing from the western tributary river and, sweeping across the lake waters, eroding away the inner portion of the 200-foot terrace and cutting downward to the 100-foot level. All the features of the topography of this complex of terraces and bluffs become harmonized on the interpretation that they represent the erosive work of Iroquois-Mohawk currents discharging into the Hudson Valley waters. The trends of direction of the bluffs bounding the erosion terraces could not have resulted from southward flowing currents of the Hudson Valley waters.

Deductions

These topographic features, due to erosion by the Iroquois-Mohawk currents, afford a datum for determining the time of subsidence of Lake Albany with reference to the location of the front of the ice-sheet in its retreat from the Hudson and Champlain valleys. The outlet of the interior glacial lakes continued through the Mohawk Valley until such time as the receding ice-front opened an outlet along the northward slope of the Adirondacks. It follows from the data above given that the subsidence of Lake Albany had proceeded to the extent that its waters had lowered from the 360-foot level (that of the Schenectady delta) to the 100-foot level (that of the lower erosion terraces at Mechanicsville) within the period of time the ice-front was in process of retreat to the northern end of the Champlain region; for during the continuance of the Iroquois-Mohawk outlet its currents lowered their bed in the Lake Albany deposits, *pari passu* with the subsidence of the lake waters, from the surface of the deposits to the level of 100 feet.

There is no evidence that the waters of the Hudson Valley, after their subsidence to the level indicated by the lower-eroded areas at Mechanicsville, rose again to a higher level. The present major topographic features of the valley—the terraces and their slopes—have certainly not been modified by overflowing waters since their origin. If, therefore, a water connection existed between the Champlain arm of the sea and the ocean at New York, this strait had a breadth at Mechanicsville not greater than approximately the space between the 100-foot contour lines on the opposite sides of the valley—that is, a breadth not greater than that of the present valley bottom.

These deductions, drawn from the facts of topography, are opposed to the conception of a body of marine waters filling the Hudson Valley to a height indicated by the river deltas and continuous with marine waters in the Champlain depression.

If we suppose that the Hudson Valley waters in which the sands and clays were deposited were estuarine, opening into the sea at New York, then that portion of the estuary included in the region of Mechanicsville had become changed to a fresh-water river while yet the Saint Lawrence basin was filled with ice. We are thus led to conclude that at no time was there a continuous body of marine waters connecting the Saint Lawrence arm of the sea with the ocean at New York.

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VOL. 30, PP. 423-470 DECEMBER 31, 1919
PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY

SIGNIFICANCE OF THE SHERBURNE SANDSTONE IN UPPER DEVONIC STRATIGRAPHY[1]

BY AMADEUS W. GRABAU

(Presented before the Paleontological Society December 31, 1917)

CONTENTS

INTRODUCTION

The Sherburne sandstone was named by Vanuxem, in 1839,[2] from the town of Sherburne, in Chenango County, New York, where, on and near the Chenango River, it is well exposed and has been extensively quarried for building and flagging purposes. The original description of this formation is very brief and refers to the group of rocks underlying the Ithaca beds of that section and overlying the Hamilton. Vanuxem states that "the stones are of various grades of thickness, alternating with greenish or olive colored shale. Fucoids resembling stems of plants are frequent in this rock and also fragments of plants like the grasses. The flagstone mass extends from Cayuga Lake through the district."

[1] Manuscript received by the Secretary of the Geological Society February 17, 1919. Dedicated to the memory of Charles S. Prosser.

[2] Fourth Annual Report, Third Geological District, New York (Assembly Document no. 275, 1839), p. 318.

Prosser[3] has given a fuller and more detailed description of this rock in the various sections from the Chenango River eastward, and these serve as a basis for our understanding of the relationship of this to the inclosing formations. More recently still, Dr. John M. Clarke has discussed certain characters of these sandstones, and to this reference will be made farther on in this paper.[4]

The typical Sherburne Sandstone

GENERAL DESCRIPTION

The rock of the type region is a bluish, rather fine-grained sandstone, frequently of the typical bluestone character, alternating with smooth shales. Near Smyrna these rocks are mostly bluish, unfossiliferous, and arenaceous shales, with thin and thick bedded sandstones with irregular markings on their upper surfaces, mainly of a mechanical nature. Some of the sandstone layers are quarried, these ranging in thickness up to 19 inches. West of Smyrna a few fossils of the Naples type, including *Pterochaenia fragile* (Hall), still occur,[5] while in the lower part there is a direct lateral passage of this Sherburne shale and sandstone into the impure Tully limestone and the sparingly represented Genesee shales. Prosser[6] ascribes the eastward disappearance of the Tully limestone "to a gradual loss of the calcareous material, which is replaced by that of the arenaceous and arigillaceous sediments, causing the rock to present a decidedly different lithologic appearance."

The total thickness of the Sherburne in the Chenango River section is about 250 feet and shales seem to predominate. While in a few sections near Smyrna a little of the Tully and Genesee are still represented, these are for the most part absent, the Sherburne resting directly upon the fossiliferous Hamilton shales and sandstones. The Sherburne itself is devoid of marine fossils, except that in this region a few intercalations of dark shales occur, usually in its lower part, which carry a remnant of the Naples fauna, so much more abundantly developed in the equivalent rocks farther west. Thus, in the gorge of Nigger Brook, 1½ miles south of Sherburne village, Prosser found blackish shales at a horizon

[3] C. S. Prosser: The classification and distribution of the Hamilton and Chemung series of central and eastern New York. 16th Ann. Rept. New York State Geologist, pt. i, pp. 87-222. Prosser calls attention to the fact that the "Sherburne" flagstone of Vanuxem's 1840 report are different from the beds comprised in the "Sherburne" group of Conrad's 1841 report, these latter belonging in the Hamilton group below the Tully limestone.

[4] John M. Clarke: Strand and undertow markings of Upper Devonian time as indications of the prevailing climate. New York State Museum Bulletin 196, April, 1917, plates 7-25, pp. 199-210.

[5] Prosser: Loc. cit., p. 119.

[6] Loc. cit., p. 118.

about 63 feet above the top of the Hamilton, carrying a few specimens of the following species:

Buchiola speciosa Hall	r
Leptodesma rogersi Hall	r
Coleolus aciculus ?	c
Orthoceras cf. *subulatum* Hall	r
Goniatites cf. *discoideus* Hall	c

This appears to be a wedge of the more fossiliferous western shales entering the unfossiliferous Sherburne sands and shales. The relationship with the fossiliferous Tully, Genesee, and Naples to the westward is shown on the following diagram:

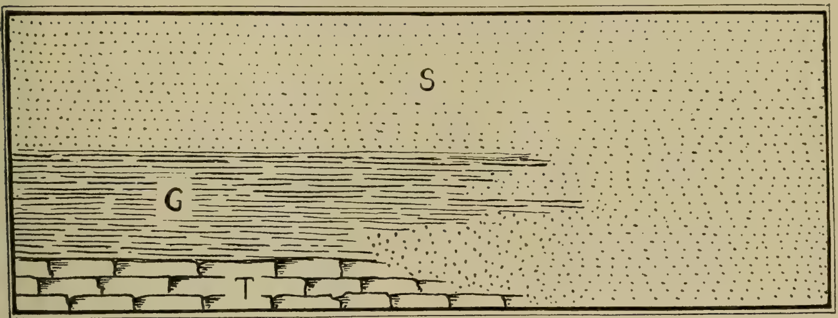

FIGURE 1.—*Diagram showing relationships of Sherburne Sands* (S) *to Genesee Shales* (G) *and Tully Limestone* (T) *in the vicinity of Sherburne Village*

Typically marine fossils are absent from the typical Sherburne sands and shales except for the wedges of Naples shales above referred to, but Dr. John M. Clarke has illustrated a fragment of this rock which, besides showing the natural relief molds of longitudinal drag-furrows and the characteristic *Fucoides graphica,* also incloses a stranded goniatite shell (*Manticoceras*). Plant remains are, however, not uncommon in the Sherburne sandstones. These are probably for the most part stipes of ferns or fernlike plants and they are represented chiefly by impressions, often more or less iron-stained. Vanuxem says of them: "They have the appearance of narrow leaf-grasses, broken into fragments, and are invariably of a brownish color.[7] These plant remains are always found on the bedding planes, where they appear to have been stranded, they having been brought to their resting place from other localities. That they did not grow *in situ* is shown by the fact that they are never upright, penetrating the layers of sandstone at right angles to the bedding plane, as would be the case were the sand and mud deposited around the standing stems of reeds or other aqueous plants. So far as can be judged

[7] Report of the Third District, 1842, p. 173.

from the remains, they are land plants and were probably swept to their present position by river currents.

Besides these undoubted plant remains, there are elongated, raised ridges on the under side of many of the sandstone layers, which represent the natural fillings or casts of depressions of similar form in the surface of the mud layer next below. These have been doubtfully referred to fucoids by Vanuxem and described as *Fucoides graphica,* because they resemble "the stiff, simple markings, excepting as to size, of the juvenile scholar."[8] They are most probably not plant remains, their character being more nearly that of depressed trails or tracks made in the surface of the mud flat. But what organism could be responsible for the making of such tracks, if tracks they are, does not appear. The absence of remains of the organism itself suggests that it was a land form, which visited this region temporarily, or else that it was soft-bodied and so left no remains. There is, however, another interpretation of these structures, recently advanced by J. M. Clarke[9] after a suggestion by J. B. Woodworth, namely, that they are groves formed by ice crystals, such as are produced by the formation of ground ice in shallow water.

EASTWARD EXTENSION OF THE HORIZON OF THE SHERBURNE SANDSTONE

Traced eastward along the outcrop, the Sherburne sandstone holds its own as far as the Unadilla River valley, some ten miles from Sherburne. It everywhere rests upon the Hamilton shales and throughout is succeeded by shales with the Ithaca fauna. The Sherburne formation consists of shales and micaceous sandstones, the latter characterized by the markings termed *Fucoides graphica* by Vanuxem. In the Unadilla River section the Tully and Genesee are absent, the unfossiliferous Sherburne sands and shales resting directly upon the fossiliferous Hamilton shales and sands. The transition from the Hamilton to the Sherburne is shown in some of the sections along the brooks entering the Unadilla near New Berlin. Prosser records the fact that in the dark shale beds immediately above the fossiliferous Hamilton "only two fragments of a goniatite and another of a different shell . . ." were found. East of the Unadilla, in Otsego and Schoharie counties, the rocks of the horizon of the Sherburne sandstone, while retaining a somewhat similar lithic character, have become more or less fossiliferous, the contained organic remains being those of the Hamilton fauna. East of the Schoharie Valley, however, in Green and Ulster counties, these beds again pass into unfossiliferous bluish and grayish sandstones with intercalated red shales, constituting the lower part of the Oneonta formation, or the Upper Flagstone

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[8] Loc. cit.

[9] J. M. Clarke: Loc. cit., pp. 205-207.

series of Ulster County, which has a total thickness of about 3,000 feet and is succeeded by the red beds of the Catskill formation. Near Noblesville, Otsego County, in the Butternut Valley, Prosser found "smooth greenish sandstones, in the midst of which are blocky shales in which *Rhynchonella* [*Hypothyris*] *venustula* Hall is common." With these occur

Spirifer mucronatus (Con.)	rr
Atrypa reticularis (Linn.)	r
Tropidoleptus carinatus (Con.)	rr

This is evidently the closing phase of Hamilton deposition, marked by the invasion of this region by *Hypothyris cuboides* just before the inauguration of the Sherburne type of sedimentation.

H. venustula is again found in this same horizon in Lawrence township, about three quarters of a mile south of Mount Vision, on the eastern side of Otego creek. Here it is associated with *Paracyclas lirata* and apparently also with *Spirifer mucronatus* and *Palæoneilo subemarginata* (?). Between the Unadilla and the Susquehanna rivers the Sherburne is still for the most part unfossiliferous, though the intercalated shales frequently carry a restricted Hamilton fauna. This is, however, more often restricted to certain levels within the formation, the great bulk of which is barren.

In Maryland township, south of the village of Schenevus, the Sherburne has yielded the following fossils about 175 feet above the Hamilton:[10]

1. *Spirifer tullius* Hall	(r)
2. *Tropidoleptus carinatus* (Con.)	
3. *Leda diversa* Hall	(r)
4. *Cypricardella tenuistriata* Hall	(rr)
5. *Palæoneilo constricta* (Con.)	(rr)
6. *Modiomorpha* cf. *subalata* var. *chemungensis* Hall	(rr)

Near Chaseville, rocks of this series, comprising shales and sandstones, have yielded, in the lower part, near the Hamilton boundary:

1. *Tropidoleptus carinatus* (Conr.)	c
2. *Spirifer mucronatus* (Conr.)	r
3. *Spirifer tullius* Hall	c

Forty-five feet higher a coarse-grained sandstone, sparingly fossiliferous, has furnished:

1. *Liorhynchus mesacostalis* Hall	(r)
2. *Crania* cf. *leoni* Hall	(c)
3. (?) *Cryptonella eudora* Hall	(rr)

[10] Prosser: Loc. cit. 16th Ann. Rept., p. 207.

Two hundred and sixty feet higher are sandstones with *Spirifer mesastrialis. S. mucronatus, Tropidoleptus carinatus,* etcetera, representing the Ithaca formation.[11]

In the section on Whitney Brook. north of Maryland, the following members are pertinent.

Twenty-five feet above the beds regarded by Prosser as forming the top of the Hamilton are bluish argillaceous and even arenaceous shales with few marine fossils, but with plenty of "fucoidal" and mud markings. These are regarded as of the horizon of the Sherburne and they contain fragments of

Spirifer mucronatus and
Liopteria dekayi—both rare.

Ten feet higher the following fauna was obtained by Prosser:

1. *Lingula punctata* Hall ?	(c)
2. *Tropidoleptus carinatus* (Con.)	rr
3. *Spirifer* sp.	rr
4. *Nuculites triqueter* Con.	rr
5. *Bellerophon* cf. *leda* Hall	rr

and plant stems referred doubtfully to

6. (?) *Rhodia pinnata* Dawson	rr

Thirty-five feet higher. or 70 feet above the top of the Hamilton, are bluish, slightly irregular shales, which inclose a 6-inch fossiliferous layer which has furnished[12]

1. *Spirifer mucronatus* (Con.)	(r)
2. Sp. *mesistrialis* Hall ?	(rr)
3. Sp. *frimbriatus* (Con.)	(rr)
4. *Chonetes setigera* Hall	(rr)
5. *Chonetes lepidus* Hall	(rr)
6. *Leptostrophia* cf. *perplana* (Con.)	(r)
7. *Lingula* sp.	(rr)
8. *Goniophora hamiltonensis* Hall	(rr)
9. *Palæoneilo constricta* (Con.)	(rr)

One hundred and thirty feet higher, or 200 feet above the top of the Hamilton, an irregular concretionary sandstone and bluish and olive shales carry the following fauna[13]

1. *Cyrtina hamiltonensis* Hall	(c)
2. *Spirifer mucronatus* (Con.)	(rr)
3. *Tropidoleptus carinatus* (Con.)	(r)
4. *Liorhynchus* sp.	(r)

[11] Prosser: Loc. cit., p. 212.
[12] Prosser: Loc. cit., p. 217.
[13] Prosser: Loc. cit., p. 217.

Fifteen feet higher is another concretionary stratum which contains Liorhynchus, and the next exposures, some distance above this, carry the Ithaca fauna and are referred to that horizon.

The equivalent of the Sherburne beds is here absolutely continuous with the Hamilton, which also contains many barren beds in its upper part. The character of the fauna of these higher beds is clearly a Hamilton one and shows the persistence in the waters east of the typical Sherburne deposits of that fauna and its slow modification by the appearance of species of the Ithaca fauna.

In the Schoharie Valley the horizon of the Sherburne is not well exposed, being mostly a greenish or grayish sandstone with alternating shales and indistinguishable lithically from the Hamilton below and the Ithaca above. Fossils are much less numerous in this region, though plant remains are not uncommon. Fossils are also much less abundant in the underlying Hamilton, where great thicknesses of barren sandstones and shales occur. The influence of the near-by Devonic land made itself felt during the deposition of the later Hamilton and succeeding beds, all of these being merely the seaward extension of the great Devonic delta of the Appalachian region, the formation of which began in Hamilton time. When fossils do occur in the Sherburne they are still of Hamilton types. Near Breakabeen bluish gray shaly sandstones 100 feet above typical Sherburne sandstone and 410 feet below red Oneonta shales carry *Tropidoleptus carinatus* in abundance, while *Spirifer mucronatus* occurs less frequently.[14] East of Breakabeen, in bluish shales 335 feet below red Oneonta beds, the following fauna occurs,[15] this being quite certainly the Sherburne, which in this region lies 500 or more feet below the Oneonta:

1.	*Camarotœchia prolifica*	(a)
2.	*Ambocœlia umbonata*	(rr)
3.	*Strophalosia truncata*	(rr)
4.	*Pterinea flabella*	(c)
5.	*Nyassa arguta*	(c)
6.	*Nuculites oblongatus*	(rr)
7.	*Palæoneilo constricta*	(rr)
8.	*Nucula bellistriata*	(rr)
9.	*Tellinopsis subemarginata*	(rr)
10.	*Tentaculites bellulus*	(r)

In the Panther Creek section, along one of the branches of the West Kill, in coarse grayish sandstones and thin blue shales, lying 140 feet below shales carrying the Ithaca fauna, Prosser found[16]

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[14] Prosser: 17th Ann. Rept. N. Y. State Geologist, 1897, p. 181.
[15] Loc. cit., p. 178.
[16] Loc. cit., p. 192.

Tropidoleptus carinatus	(r)
Spirifer sp.	(rr)
Nuculites oblongatus	(rr)

These clearly belong in the horizon of the Sherburne sandstone. In the Panther Creek valley, southwest of West Fulton, coarse shales with an abundant Hamilton fauna occur about 100 feet or a little more below shales carrying the Ithaca fauna with *Spirifer mesastrialis.* These apparently are also of the horizon of the Sherburne sandstone. On the Mill Creek highway, in arenaceous shales 215 feet below beds carrying the Ithaca fauna, Prosser found[17]

1. *Tropidoleptus carinatus*	a
2. *Chonetes coronatus*	rr
3. *Ambocœlia umbonata*	rr
4. *Camarotœchia congregata*	c
5. *C.* cf. *stevensi*	rr
6. Cephalopod fragment	rr

This though a Hamilton fauna is clearly in the rocks of the Sherburne, though perhaps in the lower part at West Blenheim, in rocks the top of the Sherburne or the base of the Ithaca (M^3 of Prosser), Prosser found the following fauna.[18]

1. *Spirifer mucronatus*	(c)
2. *Chonetes setigera*	(c)
3. *Tropidoleptus carinatus*	(r)
4. *Leda diversa*	(rr)
5. *Orthonota undulata*	(rr)
6. *Schizodus appressus*	(rr)
7. *Orbiculoidea* sp.	(rr)

This is a Hamilton fauna. Forty feet lower, in the bluish shales (M^1), Prosser found

1. *Liorhynchus multicosta* (young)	c
2. *Coleolus tenuicinctum ?*	rr

Northwest of Franklinton, in Broome township, Schoharie County, are greenish shales, 50 feet below mottled red and green shales and 115 feet below red sandstones of the Oneonta type. These shales contain a Hamilton fauna, while two loose specimens of *Spirifer mesastrialis* were found near by, probably introduced from elsewhere. The fauna in place comprises, according to Prosser,[19]

1. *Spirifer mucronatus*	(a)
2. *Spirifer granulosus ?*	(c)

[17] Loc. cit., p. 198.
[18] Loc. cit., p. 221.
[19] Loc. cit., p. 232.

3.	*Camarotœchia congregata*	c
4.	*C. prolifica ?*	rr
5.	*Chonetes coronatus*	c
6.	*C. setigerus*	r
7.	*Schuchertella chemungensis* var. *arctostriata*	c
8.	*Palæoneilo constricta*	r
9.	*Nyassa arguta*	rr
10.	*Goniophora hamiltonensis*	rr
11.	*Grammysia* sp.	rr
12.	*Orthonota parvula ?*	rr
13.	*Actinopteria boydi*	c
14.	*Glyptodesma erectum*	r
15.	*Tentaculites bellulus*	rr

From its position below the Oneonta, it is highly probable that this represents the horizon of the Sherburne sandstones farther west.

Albany County

The carefully measured section up Bradt Hollow from the valley of the Fox Kill at Peoria, in the township of Berne, Albany County, shows some interesting facts. The shales and sandstones overlying the Onondaga carry Hamilton fossils for a thickness of between 1,415 and 1,720 feet, the exact amount not being ascertainable on account of the somewhat varying dip. Seventy-five feet above the top of the highest fossiliferous zone (Prosser, 38 B^6) occurs the first horizon of red shales, marking the beginning of Oneonta sedimentation. If we consider that the Oneonta sedimentation has here entirely replaced the Ithaca, we must hold at least 175 feet of the fossiliferous beds of Hamilton type as belonging to the Sherburne. This would reduce the thickness of the Hamilton (inclusive of the Marcellus) to between 1,240 and 1,545 feet. In the neighboring Schoharie Valley, where the Sherburne representative retains its thickness of 250 feet below the Ithaca beds, the Hamilton Marcellus is figured by Prosser as 1,685 feet.[20] It must, however, be borne in mind that such measurements are not absolutely correct, on account of the variable dip of the strata.

If the whole of the fossiliferous series in Bradt Hollow Hill is of Hamilton age, then the red sedimentation (Oneonta type) has replaced more than the upper half of the Sherburne. This is not improbable, since in Ulster County the whole of the Sherburne and possibly some Hamilton is replaced by this type of sedimentation. That is due to the fact that that region is nearer to the source of supply of the continental sediments which form the Oneonta-Catskill delta, and that hence these sediments appear earlier in the geological column as we approach that region.

[20] Loc. cit., p. 190.

If we, however, regard the whole of the Sherburne as still represented in the Bradt Hollow section, then the three upper fossiliferous zones (B^7, B^6, and B^4 of Prosser) must be included in it. The highest of these zones (B^7), which lies about 75 feet below the red Oneonta shales, contains the following fauna:[21]

1. *Chonetes coronatus*	r
2. *Spirifer mucronatus*	rr
3. *Pterinea flabella*	r
4. *Actinopteria boydi*	r
5. *Nuculites oblongatus*	r
6. Bryozoans	rr

Fifteen feet lower, in thin strata of bluish to green shales, the following fauna occurs (Prosser's zone B^6):

1. *Atrypa reticularis*	c
2. *Spirifer mucronatus*	rr
3. *S. granulosus*	rr
4. *Chonetes setigera*	rr
5. *Orthonota undulata*	c
6. *Nuculites oblongatus* (small)	c
7. *Palæoneilo constricta*	rr
8. *Grammysia bisulcata*	rr
9. *Pterinopecten vertumnus*	rr

Fifty feet lower are greenish and bluish shales lithically like the Sherburne shales, but alternating with slightly fossiliferous sandstones.

Forty feet lower, or 160 feet below the lowest Oneonta bed, occur sandstones and richly fossiliferous shales with the following fauna (Prosser, zone B^4):

1. *Spirifer mucronatus*	c
2. *S. granulosus*	rr
3. *S. audaculus*	c
4. *Tropidoleptus carinatus*	r
5. *Chonetes coronatus*	r
6. *Camarotœchia sappho*	a
7. *C. congregata*	c
8. *Eunella lincklæni*	rr
9. *Productella* sp.	rr
10. *Palæoneilo constricta*	r
11. *Nuculites triqueter*	rr
12. *Tellinopsis subemarginata*	rr
13. *Sphenotus truncata*	r
14. *Orthonota undulata*	r
15. *Goniophora hamiltonensis*	r
16. *Cimitaria elongata*	rr

[21] Prosser: Loc. cit., p. 243.

17.	*Modiomorpha subalata*	rr
18.	*Elymella levata*	rr
19.	*Cypricardella tenuistriata*	rr
20.	*Actinopteria boydi*	c
21.	*Liopteria dekayi*	c
22.	*Pterinopecten vertumnus*	c
23.	*Homalonotus dekayi*	rr
24.	*Tæniopora exigua*	c
25.	*Lingula* sp.	rr
26.	*Nucula corbuliformis*	rr

From these lists it appears that either the Sherburne horizon is here in part represented by the continental sediments of the Oneonta type or else it carries a typical Hamilton fauna. I am inclined to regard the latter as the true interpretation, since this section is as far removed from the center of deposition of the Oneonta sands and muds as is that of Moheganter Hill, where the Sherburne is still fully represented.

Southeastern New York

In the Port Jervis region, near the New York, Pennsylvania, New Jersey boundary, the Sherburne beds contain a typical residual Hamilton fauna. A short distance above sandy beds which carry an abundant and typical Hamilton fauna Prosser found ledges of "thin flaggy stones which split into layers between one-half and one inch in thickness. The stone is very arenaceous, of slightly greenish tint, and may be called a sandstone with very thin layers." It contains the following fauna:[22]

1.	*Spirifer mucronatus*	aa
2.	*Tropidoleptus carinatus*	a
3.	*Chonetes mucronatus*	rr
4.	*C. setigerus*	rr
5.	*Cyrtina hamiltonensis*	rr
6.	*Cypricardella gregarius*	c
7.	*Paracyclas lirata*	rr
8.	*Modiomorpha subalata*	rr
9.	*Actinopteria boydi*	rr
10.	*Palæoneilo constricta*	rr

Summaries of Faunas

An analysis of the faunal lists given in the preceding pages and obtained from the fossiliferous beds of the Sherburne east of the Unadilla River shows that it is still a true Hamilton fauna, albeit a selected fauna,

[22] C. S. Prosser: Am. Jour. Sci., 3d ser., vol. 46, p. 212. Bull. U. S. Geol. Surv., no 120, p. 308.

from which many of the typical Hamilton species are missing. This is clearly shown in the following table, in which rr = very rare; r = rare; rc = fairly common; c = common; x = present:

Table I.—Table of Species Found in the Eastern Sherburne

	Eastern Sherburne						
Brachiopods	Number of Stations	Abundance	Hamilton	Western Sherburne	Western Ithaca	Eastern Ithaca	Chemung
1. *Tropidoleptus carinatus*	10	c	x	—	—	x	—
2. *Spirifer tullius*	2	rc	x	—	—	x	—
3. *Spirifer granulosus* ?	3	rc	x	—	—	x	—
4. *S. mucronatus*	11	c	x	—	—	x	—
5. *S. audaculus*	1	c	x	—	—	—	—
6. *S. mesistrialis* ?	1	rr	—	—	x	x	x
7. *S. fimbriatus*	1	rr	x	—	x	x	—
8. *Liorhynchus multicostus*	1	c	x	—	—	—	—
9. *L. mesicostalis*	1	r	—	x	x	x	x
10. *Cyrtina hamiltonensis*	2	rc	x	x	x	x	—
11. *Crania* cf. *leoni*	1	c	—	—	—	—	x
12. *Cryptonella eudora* ?	1	rr	x	—	x	—	—
13. *Eunella lincklaeni*	1	rr	x	—	—	x	—
14. *Lingula punctata* ?	1	c	x	—	x	—	—
15. *Chonetes coronatus*	4	rc	x	—	—	x	
16. *C. setigerus*	5	rc	x	—	—	x	—
17. *C. lepidus*	1	rr	x	x	x	x	—
18. *C. mucronatus*	1	rr	x	—	—	?	—
19. *Leptostrophia* cf. *perplana*	1	r	x	—	—	—	—
20. *Camarotoechia prolifica*	2	c	x	—	—	—	—
21. *C. congregata*	3	c	x	—	—	—	—
22. *C. sapho*	1	a	x	—	—	—	x
23. *C.* cf. *stephani*	1?	rr	—	—	x	x	x
24. *Ambocoelia umbonata*	2	rr	x	x	x	x	—
25. *Strophalosia truncata*	1	rr	x	—	x	x	—
26. *Schuchertella chemungensis arctostriata*	1	c	x	—	—	x	
27. *Atrypa reticularis*	2	rc	x	—	x		

Pelecypoda

28. *Leda diversa*	2	r	x	x	x	x	
29. *Cypricardella tenuistriata*	2	rr	x	—	x	x	
30. *C. gregaria*	1	c	x	—	x	x	—
31. *Palaeoneilo constricta*	7	r	x	x	x	x	x
32. *Grammysia bisculcata*	1	rr	x	—	—	x	
33. *Modiomorpha subalata chemungensis*	1	rr	—	x	x	x	x
34. *Modiomorpha subalata*	2	rr	x	x	x	x	—
35. *Liopteria dekayi*	2	rc	x	—	—	x	
36. *Nucula bellistriata*	1	rr	x	—	—	x	
37. *N. corbuliformis*	1	rr	x	—	x	x	
38. *Nuculites triqueter*	2	rr	x	—	x	x	
39. *Nuculites oblongatus*	4	rc	x	—	—	x	
40. *Goniophora hamiltonensis*	3	r	x	—	x	x	

Table I.—Continued.

Pelecypoda—Continued.	Eastern Sherburne: Number of Stations	Eastern Sherburne: Abundance	Hamilton	Western Sherburne	Western Ithaca	Eastern Ithaca	Chemung
41. *Cimitaria elongata*	1	rr	x	—	—	—	—
42. *Pterinea flabella*	2	rc	x	—	—	—	—
43. *Pterinopecten vertumnus*	2	rc	x	—	—	x	—
44. *Nyassa arguta*	2	rc	x	—	—	x	—
45. *Elymella levata*	1	rr	x	—	—	—	—
46. *Tellinopsis subemarginata*	2	rr	x	—	—	x	—
47. *Orthonota undulata*	3	rc	x	—	—	x	—
48. *O. parvula* ?	1	rr	x	—	—	x	—
49. *Schizodus appressus* (*S. chemungensis*)	1	rr	x	—	—	x	x
50. *Actinopteria boydi*	4	c	x	—	x	x	
51. *Glyptodesma erectum*	1	r	x	—	—	x	—
52. *Sphenotus truncatus*	1	r	x	—	—	x	—
53. *Paracyclas lirata*	1	rr	x	—	—	x	—
Bryozoa							
54. *Taeniopora exigua*	1	c	x	—	—	—	—
55. *Bellerophon* cf. *leda*	1	rr	x	—	—	x	—
Pteropoda							
56. *Tentaculites bellulus*	2	r	x	—	—	—	—
57. *Coleolus tenuicinctum* ?	1	rr	x	—	—	x	—
Trilobitae							
58. *Homalonotus dekayi*	1	rr	x	—	—	x	—
Plantae							
59. *Rhodea pinnata* ?	1	rr	x	—	—	x	—

The most frequently occurring species of Brachiopoda are *Tropidoleptus carinatus* and *Spirifer mucronatus,* while *Chonetes coronatus* and *Chonetes setigera* come next. Other species recorded from more than one locality or subhorizon are:

Spirifer tullius (2)
S. granulosus (3)
Camarotœchia congregata (3)
C. prolifica (2)
Ambocœlia umbonata (2)

The pelecypods likewise show the Hamilton character. Of these *Palæoneilo constricta* is the most frequently found, the next being *Nuculites oblongatus*. Other species occurring more than once are *Leda diversa* (2); *Cypricardella tenuistriata* (2); *Liopteria dekayi* (2); *Nuculites triqueter* (2); *Goniophora hamiltonensis* (2); *Pterinea flabella* (2); *Pterinopecten vertumnus* (2); *Nyassa arguta* (2); *Tellinopsis subemarginata* (2); *Orthonota undulata* (3); *Actinopteria boydi* (3).

Of other species only *Tentaculites bellulus, Coleolus tenuicinctum, Bellerophon* cf. *leda, Homalonotus dekayi,* and *Tæniopora exigua* occur, the first twice, the others in only one section each.

The table shows that out of the 59 species identified from the eastern Sherburne, 54, or about 91 per cent, are characteristic Hamilton fossils. Of the 5 remaining species, three brachiopods—*Spirifer mesistrialis, Crania leoni,* and *Camarotœchia stephani*—are doubtfully identified, while the other brachiopod, *Liorhynchus mesicostalis,* occurs in only one locality and is rare. Moreover, this may be a local development of the specific character from *L. multicosta* by the obsolescence of the lateral plications. The only post-Hamilton pelecypod *Modiomorpha subalata* var. *chemungensis,* of which only a single specimen was found, and that not of the typical form. Thus this eastern Sherburne fauna may be regarded as a persistent Hamilton one.

The Sherburne Horizon West of the Chenango Valley

Westward from the Chenango Valley, to the meridian of Cayuga Lake, the "Lower Portage" beds which overlie the Genesee are for the most part sandstones and represent the horizon of the Sherburne, by which name they have come to be known. On Cayuga Lake these beds exhibit the remarkable jointing which Vanuxem, Hall, and Dana have illustrated and which has generally been regarded as the best example of prismatic jointing in stratified rocks. The thickness of these Lower Portage beds is approximately 250 feet.

The fauna which has so far been obtained from these beds is listed in the second column of the table on page 437. The list is compiled from the studies of Kindle on this region, which is perhaps the most exhaustive so far made.[23] The Ithaca species of the type section are also included in the first column of this list. In the third column are given the species which also occur in the Sherburne east of the Unadilla region, while the fourth column shows those which occur in the Hamilton beds

[23] Bull. Am. Pal., vol. ii, December, 1896. Also, "Note on the range and distribution of *Reticularia lævis*." Journ. Geol., vol. 14, 1906, pp. 188-193.

of New York as well. The fifth column shows the species also found in the Naples beds, and the sixth those also found in the Chemung. In column 7 the forms also occurring in the Iowan region are listed, while the final column, 8, contains those also found in the eastern Ithaca.

In the following table, rr = very rare; r = rare; rc = fairly common; c = common; cc = very common; x = present.

Table II.—Ithaca Species of Ithaca

	Ithaca of Ithaca	Sherburne of Ithaca	Eastern Sherburne	Hamilton	Naples	Chemung	Iowan	Eastern Ithaca
	1	2	3	4	5	6	7	8
Coelenterata								
1. *Stromatopora*	r							
2. *Aulopora*	c	c						
3. *Cladochonus*	—	c						
4. *Zaphrentis simplex* Hall	r	—	—	x				
Bryozoa								
5. *Callopora* sp	c							
6. *Cystodictya meeki* Nich	cc	—	—	x				
Brachiopoda								
7. *Ambocoelia umbonata* Conrad	cc	rc	r	x	—	x	—	x
8. *Atrypa reticularis* Linne	c	—	c	x	—	x	x	x
9. *A. spinosa* Hall	c	—	—	x	—	x	—	—
10. *Camarotoechia contracta* Hall	rc	—	—	—	—	x	—	x
11. *C. eximia* Hall	c	rc	—	—	—	x	—	x
12. *C. stephani* Hall	c	—	—	—	—	x	—	x
13. *Chonetes lepidus* Hall	rc	c	rr	x	—	x	—	x
14. *C. scitulus* Hall	r	r	—	x	x	x	—	x
15. *Craniella hamiltoniae*	rc	rc	—	x	—	—	—	—
16. *Cryptonella eudora* Hall	c	—	rr	x	—	x	—	—
17. *Cyrtina hamiltonensis* Hall	cc	rc	c	x	—	—	—	x
18. *Liorhynchus mesicostalis* Hall	cc	rc	r	—	—	x	—	x
19. *Lingula complanata* H. S. W	cc	—	—	x	—	—	—	—
20. *L. ligea* Hall	r	—	—	x	x	—	—	—
21. *L. punctata* Hall	r	—	c	x	—	—	—	—
22. *L. spatulata* Hall	r	—	—	—	x	—	—	—
23. *Orbiculoidea neglecta* Hall	r	—	—	—	—	—	—	x
24. *Productella hallana* Walcott	r	—	—	—	—	—	x	—
25. *P. speciosa* Hall	cc	—	—	—	x	x	—	x
26. *Pugnax pugnus* (Martin)	rc	rc	—	—	—	—	x	—
27. *Roemerella grandis* ? Hall	r	—	—	x	—	—	—	—
28. *Schizophoria impressa* Hall	c	—	—	—	—	x	x	—
29. *Spirifer angusta* Hall	r	—	—	x	—	—	—	—

Table II—continued

Brachiopa—Continued	Ithaca of Ithaca 1	Sherburne of Ithaca 2	Eastern Sherburne 3	Hamilton 4	Naples 5	Chemung 6	Iowan 7	Eastern Ithaca 8
30. *S.* (*Reticularia*) fimbriata Mart	r	—	r	x	—	—	x	—
31. *S.* (*Reticularia*) *laevis* Hall	rc	c	—	—	—	x	—	—
32. *S. mesistrialis* Hall	cc	—	?	—	—	x	—	x
33. *S. mucronatus* var. *posterus*	cc	—	—	—	—	x	—	x
34. *Strophalosia truncata* Hall	c	—	rr	x	—	—	—	x
35. *Stropheodonta demissa* ? Hall	r	—	—	x	—	—	—	x
36. *S. mucronata* Hall	cc	c	—	—	—	x	—	x
37. *S. perplana* var. *nervosa* Hall	c	—	—	—	—	x	—	—
Pelecypoda								
38. *Actinopteria boydi* Hall	cc	—	c	x	—	—	—	x
39. *A. perstrialis* Hall	c	c	—	—	—	—	—	—
40. *A. tenuistriata* Hall	r	r	—	—	—	—	—	—
41. *Aviculopecten cancellatus* Hall	r	—	—	—	—	x	—	—
42. *A. fasciculatus* Hall	r	—	—	x	—	—	—	—
43. *A. lautus* var. *ithacaensis* Kindle	—	r	—	—	—	—	—	—
44. *A. rugaestriatus* ? Hall	r	r	—	—	—	x	—	—
45. *A. striatus* ? Hall	rc	—	—	—	—	—	—	—
46. *Buchiola retrostriata* (von Buch)	r	—	—	—	x	—	—	—
47. *Conocardium liratum* Hall	r	—	—	—	—	—	—	—
48. *Edmondia subovata* Hall	c	—	—	—	—	x	—	x
49. *Glossites depressus* Hall	rc	r	—	—	—	x	—	x
50. *Goniophora hamiltonensis* Hall	rc	—	rr	x	—	—	—	x
51. *G. minor* Hall	c	—	—	—	—	—	—	—
52. *Grammysia subarcuata* Hall	c	rc	—	—	—	x	—	x
53. *Leda curta* ? Meek	—	r	—	—	—	—	—	—
54. *L. diversa* Hall	c	c	r	x	—	—	—	x
55. *L. perstriata* Hall	—	r	—	x	—	—	—	—
56. *Leptodesma naviforme* Hall	r	—	—	—	—	—	—	—
57. *L. sociale* Hall	rc	c	—	—	—	x	—	—
58. *L. sp.* ?	r	—	—	—	—	—	—	—
59. *Macrodon chemungensis* ? Hall	r	—	—	—	—	x	—	—
60. *Microdon* (*Cypricardella*) *bellistriatus* (Conrad)	c	—	—	x	—	x	—	x
61. *M.* (*Cypricardella*) *gregarius* Hall	rc	—	—	—	—	x	—	x
62. *M.* (*Cypricardella*) *tenuistriatus* Hall	r	—	rr	x	—	—	—	x
63. *Modiomorpha complanata* Hall	r	—	—	x	—	—	—	x
64. *M. concentrica* Hall	r	—	—	x	—	—	—	x
65. *M. neglecta* ? Hall	rr	—	—	—	—	x	—	—
66. *M. subalata* Hall	rc	rc	c	x	—	—	—	x
67. *M. subalata* var. *chemungensis* Hall	cc	r	rr	—	—	x	—	x
68. *Mytilarca chemungensis* Hall	c	c	—	—	—	x	—	—
69. *M. umbonata* Hall	r	—	—	—	—	x	—	—
70. *Nucula corbuliformis* Hall	r	—	rr	x	—	—	—	x
71. *N. diffidens* Hall	c	c	—	—	—	x	—	—
72. *N. lamellata* Hall	rr	—	—	x	—	—	—	—
73. *Nuculites triqueter* Conrad	rr	—	rr	x	—	—	—	x
74. *Palaeoneilo constricta* (Conrad)	c	c	r	x	x	x	—	x
75. *P. constricta* var. *flexuosa* (Conrad)	r	—	—	x	—	—	—	x
76. *P. emarginata* ? (Conrad)	r	—	—	x	—	—	—	x
77. *P. filosa* Conrad	c	c	—	—	—	x	—	—
78. *P. plana* Hall	rc	—	—	x	—	—	—	x
79. *Panenka* sp	rr	—	—	—	—	—	—	—
80. *Pararca* sp	r	—	—	—	—	—	—	—

Table II—continued

Pelecypoda—Continued	Ithaca of Ithaca	Sherburne of Ithaca	Eastern Sherburne	Hamilton	Naples	Chemung	Iowan	Eastern Ithaca
	1	2	3	4	5	6	7	8
81. *Pholadella radiata* Hall	r	—	—	x	—	—	—	x
82. *Phthonia cylindrica* Hall	rr	—	—	x	—	—	—	—
83. *P. lirata* Hall	r	—	—	x	—	—	—	—
84. *Pterinea* (*Vertumnia*) *reproba* Hall	c	—	—	—	—	—	—	—
85. *Pterinopecten erectus* Hall	r	—	—	—	—	—	—	—
86. *P. suborbicularis* Hall	r	—	—	—	—	—	—	x
87. *Pterochaenia fragilis*	r	r	—	—	x	x	—	x
88. *Ptychodesma nanum* Hall	r	—	—	—	—	—	—	—
89. *Schizodus chemungensis* Hall	c	—	—	—	—	x	—	—
90. *S. chemungensis* var. *quadrangularis* Hall	rc	—	—	—	—	x	—	—
91. *Spathella typica* Hall	c	c	—	—	—	x	—	—

Gastropoda

92. *Bellerophon explanatus* ? Hall	r	—	—	—	—	—	—	—
93. *B. ithacaenis* Kindle	r	—	—	—	—	—	—	—
94. *B. leda*	r	—	—	x	—	—	—	—
95. *Diaphorostoma lineatum var. callosa* Hall	c	—	—	x	—	—	—	—
96. *Euomphalus* (*Straparollus*) *hecale* Hall	r	—	—	—	—	x	—	—
97. *Loxonema delphicola* Hall	c	—	—	x	—	—	—	—
98. *Macrocheilus* (*Holopea*) *macrostomus* ? Hall	rr	—	—	x	—	x	—	—
99. *Platyceras carinatum* Hall	c	—	—	x	—	—	—	—
100. *Pleurotomaria capillaria* Hall	c	c	—	x	—	—	—	x
101. *Porcellia nais* Hall	r	—	—	—	—	—	—	—

Pteropoda

102. *Coleolus aciculum* Hall	c	c	—	—	x	—	—	x
103. *Coleoprion* sp	—	r	—	—	—	—	—	—
104. *Conularia congregata* Hall	rc	—	—	—	—	—	—	—
105. *Hyolithus aclis* Hall	—	r	—	x.	—	—	—	x
106. *Styliolina fissurella* Hall	r	r	—	—	x	—	—	—
107. *Tentaculites spiculus* Hall	r	—	—	—	—	x	—	x

Cephalopoda

108. *Gomphoceras tumidum* Hall	c	r	—	—	—	x	—	—
109. *Goniatites complanatus* Hall	—	c	—	x	—	—	—	—
110. *Goniatites discoideus* Hall	—	c	—	x	—	—	—	—
111. *G.* (*Manticoceras*) *simulator* Hall	r	—	—	—	x	—	—	—
112. *G. sinuosus* Hall	rc	rc	—	—	x	—	—	—
113. *G.* (*Tornoceras*) *peracutus* Hall	rr	—	—	—	x	—	—	—
114. *G.* (*Tornoceras*) *uniangulare* Con. ?	r	—	—	x	x	—	—	—
115. *Orthoceras anguis* Hall	—	r	—	—	—	—	—	—
116. *O. bebryx var. cayuga* Hall	cc	—	—	—	—	x	—	—
117. *O. demus* Hall	r	—	—	—	—	x	—	—
118. *O. fulgidum* Hall	r	—	—	—	—	—	—	—
119. *O. leander* Hall	r	—	—	—	—	x	—	—
120. *O. pacator* Hall	r	—	—	—	x	—	—	—
121. *O. pertextum* Hall	r	—	—	—	—	—	—	—

Table II—continued	Ithaca of Ithaca	Sherburne of Ithaca	Eastern Sherburne	Hamilton	Naples	Chemung	Iowan	Eastern Ithaca
Crustacea	1	2	3	4	5	6	7	8
122. *Mesothyra oceani* Hall	—	r	—	—	—	—	—	—
123. *Phacops rana* Hall	cc	—	—	x	—	—	—	x
Echinodermata								
124. *Arthracantha ithacaensis* H. S. W	c	—	—	—	—	—	—	—
125. *Poteriocrinus clarkii* var. *alpha* H. S. W	r	—	—	—	—	—	—	—
126. *P. cornellianus* H. S. W	r	—	—	—	—	—	—	—
127. *P.* (*Decadocrinus*) *gregarius* H. S. W	r	—	—	—	—	—	—	—
128. *P.* (*Decadocrinus*) *zethus* H. S. W	—	?	—	—	—	—	—	—
129. *Taxocrinus curtus* H. S. W	—	r	—	—	—	—	—	—
130. *T. ithacaensis* H. S. W	rr	—	—	—	—	—	—	—
131. *T. ithacaensis* var. *alpha* H. S. W	r	—	—	—	—	—	—	—
Pisces								
132. *Dipterus ithacaensis* H. S. W	r	—	—	—	—	—	—	—
Plantae								
133. *Plumulina plumularia* Hall	c	rc	—	—	—	—	—	—
134. *Lepiodendron* sp	r	—	—	—	—	—	—	x
135. *Psilophyton princeps* Dawson	c	c	—	—	—	—	—	x
136. *Radiopteris punctata* Dawson	r	—	—	—	—	—	—	—

It will be observed that out of a total of 45 species recorded for the Sherburne or Lower Portage of the Ithaca region, 13 are Hamilton forms, but only 8, or a little less than 18 per cent of the whole, occur also in the eastern Sherburne. Of these, 6, or 75 per cent, are typical Hamilton species and only 2, *Modiomorpha subalata chemungensis* and *Liorhynchus mesicostalis*, are super-Hamilton types. The first of these is a single specimen of a shell "larger and longer . . . than any of the figures of the . . . species" . . . found with a Hamilton fauna 175 feet above the last occurrence of a typical Hamilton fauna in Maryland township, Otsego County. The other is represented by several specimens from sandstones 100 feet above beds with a typical Hamilton fauna near Schenevus, also in Otsego County. It is not impossible that these may both be in the base of the Ithaca, a part of what has been classed as Upper Hamilton being actually basal Sherburne.

[24] Dominant species of Ithaca formation at Ithaca, called by Williams "*Productella speciosa* fauna" (Williams, Bull. U. S. Geol. Survey, 210, p. 74).

In any case, these species—providing their identification is correct, which is at least doubtful in the case of the Modiomorpha—do not offer any serious argument against the conclusion that the fauna of the Sherburne east of the Unadilla and that of the same horizon west of the Chenango River are distinct, the former remaining a typical Hamilton fauna, the latter becoming a modified fauna, influenced in part by the Naples fauna of the region farther west, of which it contains several of the most characteristic species. Judging from analogy with modern faunas, we may conclude that the eastern region was in constant connection with the center of distribution of the Hamilton fauna, and so remained true to type, while the western region was almost entirely cut off from the further immigration of Hamilton types, and so became modified into a provincial fauna.

The barrier which effected this separation was the non-marine phase of the Sherburne—that is, the typical Sherburne—which is now shown between the Unadilla and Chenango rivers of New York. This appears to have been a low sand bar about 10 miles across, which extended from the mainland to the north as a prolonged bar or sand spit across New York. To the south this bar extended into the region of black mud deposition, which served to complete the barrier.*

This is essentially the bar previously outlined by Dr. John M. Clarke (New York State Museum Memoir 6, Plate A), though he has not attempted to show its relationship south of New York State. In early Portage time the eastern area was still connected with the Atlantic by way of the Champlain-Saint Lawrence channel.

If we now consider the 32 species recorded from the western Sherburne which are not persistent Hamilton types, we can refer most of them to a probable ancestor in the Hamilton. Two of the corals, *Aulopora* and *Cladochonus,* are not specifically identified, and the same is true of one pteropod. Two others are plants which may also occur in the Hamilton. This leaves 27 species to be accounted for. They will now be considered *seriatim.*

Brachiopoda

11. *Camarotœchia eximia* Hall

> This appears to be a derivative of *C. prolifica* of the Hamilton, which species the young of the present form resembles. The main difference is in the finer plications of the later species, while the fold and sinus develop at a much later stage. This species apparently does not extend beyond the Ithaca beds.

* See map, p. 955, fig. 3, this Bulletin, vol. 28.

18. *Liorhynchus mesicostalis* Hall

This species also occurs in the Devonic of the Ural Mountains of Russia, but has not been reported from western America. It is characteristic of the Chemung and has also been observed in the eastern "Sherburne." This form, as Hall says, may readily be derived from *L. quadricosta* and *L. multicosta* of the Hamilton by suppression of the lateral plications. Variations within the Hamilton species not infrequently lead to such obsolescence. The specimens from the eastern Sherburne may thus be independently derived.

26. *Pugnax pugnus* (Martin)

This is clearly an invader from the western fauna which characterized the Dakota Sea. Its appearance in the upper part of the Sherburne is remarkable. It occurs again 240 and 400 feet above this formation in the Ithaca. Its latest invasion seems to be with the High Point fauna.

31. *Reticularia lævis* Hall

This, the most characteristic species of the western Sherburne, is a derivative from the Hamilton species, *R. fimbriata*. As shown by H. S. Williams,[25] some specimens of *R. lævis* still show the fimbriated plicæ near the anterior margin. The process seems to have been one of retardation, the plicæ appearing later and later, until in most cases they did not appear at all.

36. *Stropheodonta mucronata* Hall

This species appears to be a direct derivative of *S. perplana* of the Hamilton group. The variety *tullius* of the Tully limestone is, according to H. S. Williams, an intermediate form between the two.

Pelecypoda

39. *Actinopteria perstrialis* Hall
40. *Actinopteria tenuistriata* Hall

Two small species derivable from Hamilton ancestors.

43. *Aviculopecten lautus* var. *ithacænsis* Kindle

Derived without doubt from the Hamilton species *A. lautus*.

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[25] H. S. Williams: The life history of *Spirifer lævis*. New York Academy of Sciences Annals, vol. ii, no. 6, 1882, pp. 140-160.

44. *Aviculopecten rugæstriatus* Hall

Undoubtedly derived from Hamilton species of the genus, of which there are several rather closely related ones.

49. *Glossites depressus* Hall

Not unlike the Hamilton *G. subtenuis* from which it may be derived.

52. *Grammysia subarcuata* Hall

This seems to be a derivative of the Hamilton *G. arcuata,* with which the young agrees. In the adult it is more elongate and has a more pronounced cincture than the Hamilton species.

53. *Leda (Nuculana) curta* Meek

This was described from the Saint Louis limestone. It is probably a mistaken identification.

57. *Leptodesma sociale* Hall

This might readily be a modification of *L. rogersi* of the Hamilton.

67. *Modiomorpha subalata* var. *chemungensis* Hall

This is a modification of the characteristic species of the Hamilton group. The main change is in proportion, the variety being larger.

68. *Mytilarca chemungensis* Conrad

The derivation of this form is not clear.

71. *Nucula diffidens* Hall

This appears to be derived from *Nucula yandelli* of the Hamilton, which the young stages suggest.

77. *Palæoneilo filosa* (Conrad)

Allied to *P. fecunda* of the Hamilton group, from which it apparently is derived.

87. *Pterochænia fragilis* Hall

This is an immigrant from the Naples fauna in the western part of the State.

91. *Spathella typica* Hall

The derivation of the form is doubtful.

Pteropoda

102. *Coleolus aciculum*

An immigrant from the Naples fauna.

106. *Styliolina fissurella* Hall

An immigrant from the Naples fauna.

Cephalopoda

108. *Gomphoceras tumidum* Hall

Affinities not ascertainable.

112. *Goniatites sinuosus* Hall

An immigrant from the Naples fauna to the west.

115. *Orthoceras anguis* Hall

Possibly derived from *O. aulax* of the Hamilton, a related though larger species.

Crustacea

122. *Mesothyra oceani* Hall

Probably one of the river phyllocarids of the period.

Echinodermata

These are all new forms and, as the crinoid fauna of the Hamilton is still little known, no comparison can be made.

It is thus seen that, where comparisons are possible, newly appearing species, when not immigrants from the Naples fauna or the western (Iowan) fauna, are all referable back to some Hamilton ancestor. This is extremely significant and shows that the connection with the main abiding place of the Hamilton fauna was severed. That this abiding place was to the east is shown by the persistence there in unchanged condition of the Hamilton fauna in post-Hamilton time. I place this center of distribution in the Atlantic. That the Sherburne bar was effective in keeping the new formed fauna out of the eastern area is shown by a comparison of species. That it disappeared as a barrier after the deposition of 250 feet of sandstone is shown not only by the fossiliferous character of the beds overlying the typical Sherburne of the Chenango-Unadilla region, but also by the fact that then the persistent

Hamilton species could invade the Ithaca region while the new formed species of that province spread eastward into the area formerly held by a pure Hamilton fauna. This mixed fauna is the Ithaca fauna, and that it is composed of the mingling of the pure Hamilton fauna from the east and the provincialized and modified Hamilton fauna from the Ithaca region is seen in the preponderance of the latter type of species in the Ithaca fauna of the type region and of the Hamilton species in the Ithaca fauna of the east.

The Ithaca Fauna

The Ithaca beds and fauna were first named by H. S. Williams from the occurrence of this fauna above the Lower Portage (Sherburne) in the Ithaca region. It was a fortunate coincidence that the fauna was named from this region, since its distinctive species developed here, as first pointed out by Dr. J. M. Clarke, occupying at first in their purity the Sherburne or Lower Portage beds. Then the Ithaca congeries was formed by the commingling of this fauna with the Hamilton fauna from the east. The Ithaca fauna ranges here through a considerable thickness of strata and is finally replaced by the Chemung fauna. Westward, as shown by John M. Clarke, the corresponding Portage beds carry the Naples fauna, from which Ithaca species are, however, excluded.

A study of the table on page 437 brings out the following facts: Of the 124 forms listed, 7 are not specifically identified, leaving 117 species. Of these 10 are doubtful, 6 being Hamilton forms. There thus remain 107 identified species from the Ithaca formation of Ithaca. Of these 30, or 36.45 per cent are Hamilton species, 12 are Naples species, but 3 of these are also Hamilton forms, leaving 9, or 8.41 per cent, added from the Naples fauna. Finally, there are 3 pure Iowan types. This makes a total of 51 "foreign" species in the Ithaca, leaving 56 indigenous ones. Of these 18 occur in the Lower Portage or Sherburne of the Ithaca region, leaving 38 new forms not yet accounted for. When compared with the Hamilton species, nearly all can be recognized as derivatives from that fauna, as was the case with the modified species of the underlying Sherburne. In the following list it is attempted to refer these species to their nearest Hamilton relative.

Brachiopoda

10. *Camarotœchia contracta* Hall

There are several Hamilton species from which this could be derived. Possibly *C. dotis* most nearly fulfills the requirements for an ancestor.

12. *C. stephani* Hall

This may have a similar ancestry.

23. *Orbiculoidea neglecta* Hall

This is so far known only from the Ithaca group. It may readily be a descendant of one of the regular Hamilton types like *O. seneca,* with which Hall compares it, or perhaps *O. doria.*

24. *Productella hallana* Walcott

This is a species derived from the Iowan and farther west Upper Devonic. It occurs in the High Point fauna. At Ithaca it occurs 380 feet above the Sherburne.

25. *Productella speciosa* Hall

This species, like the preceding, may be of western origin. It is not impossible that it is derived from some of the species of the Traverse group. Its derivation from typical Hamilton forms is not, however, excluded. Its young has fewer spines, like some of the smoother mid-Devonic species. It occurs also in the Naples fauna.

28. *Schizophoria impressa* Hall

This, like all the Middle Devonic schizophorias, seems to be an immigrant from the west, occurring first in the Tully (*S. tulliensis*). It is not characteristic of the typical Hamilton.

32. *Spirifer mesistrialis* Hall

This, according to H. S. Williams,[26] is a derivative from the Upper Hamilton, *S. tullius,* a form also characteristic of the Tully.

33. *Spirifer mucronatus* var. *posteus*

This is a modification of the ubiquitous *S. mucronatus* of the Hamilton group. It often shows a median plication in the sinus, as is not infrequently the case in some Traverse group mutations of this species.

37. *Stropheodonta* (*Leptostrophia*) *perplana* var. *nervosa* Hall

This is a derivative of the Hamilton form characterized by the irregular and often noded striæ. The young has the characters of *S. perplana.* It sometimes shows strongly mucronate cardinal angles.

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[26] Bull. Geol. Soc. Am., vol. 1, p. 491.

Pelecypoda

41. *Aviculopecten cancellatus* Hall

This may be a derivative of one of the small aviculopectens of the Hamilton, such as *A. idas* or *A. scabridus,* with which the young of our species agree in form.

45. *Aviculopecten striatus* Hall

Of Hamilton ancestry.

47. *Conocardium liratum* Hall

Probably derived from *C. denticulatum* of the Hamilton.

48. *Edmondia subovata* Hall

The species of Edmondia are all post-Hamilton and are probably immigrants from some western fauna.

51. *Goniophora minor* Hall

A small form—undoubtedly derived from a Hamilton species of the genus.

56. *Leptodesma naviforme* Hall

Derived from some Hamilton species of the genus.

59. *Macrodon chemungensis* Hall

Clearly derived from *M. hamiltoniæ,* with which the young agree closely.

61. *Microdon (Cypricardella) gregarius* Hall

This is a modification of *M. bellistriatus* of the Hamilton. It occurs in the Upper Hamilton and passes into the Ithaca and Chemung.

65. *Modiomorpha neglecta* Hall

Probably derived from *M. subalata.*

69. *Mytilarca umbonata* Hall

Derivation doubtful.

75. *Palæoneilo flexuosa* (Conr.)

A modification of the Hamilton *P. constricta.*

84. *Pterinea* (*Vertumnia*) *reproba* Hall

This, too, seems to be a derivative of the Hamilton *Pterinopecten* of the *vertumnus* type, or it may be a modification of the preceding form.

85. *Pterinopecten erectus* Hall

This is likewise a derivative of the Hamilton species, probably *P. vertumnus*, with which the young seems to agree.

86. *Pterinopecten suborbicularis* Hall

Derived from one of the numerous Hamilton species of the genus.

88. *Ptychodesma nanum* Hall

The related Hamilton species is *P. knappianum* Hall.

89. *Schizodus chemungensis* Conrad

This, as Hall suggests, is closely related to *S. appressus* of the Hamilton, being "probably only a variety of that species, which lived under different conditions."

90. *S. chemungensis* var. *quadrangularis* Hall

A modification of the preceding.

Gastropoda

92. *Bellerophon explanatus* Hall

Possibly a Hamilton form or derived from such a form as *B. natator*.

93. *B. ithacaensis* Kindle

Affinities not ascertained.

96. *Euomphalus hecale* Hall

Seems to be most nearly related to *E. inops* of the Schoharie.

101. *Porcellia nais* Hall

Probably a derivative of the Hamilton (Delaware limestone) species, *P. hertzeri* Hall.

Pteropoda

104. *Conularia congregata* Hall

This may be a derivative of *C. cayuga* or *C. continens,* both of the Hamilton group.

107. *Tentaculites spiculus* Hall

This, though smaller, may be a derivative of *T. bellulus* of the Hamilton.

Echinodermata

The species of crinoids found in the Ithaca all appear for the first time. Their relationships to other species are not known.

Cephalopoda

116. *Orthoceras bebryx* var. *cayuga* Hall

A modification of *O. bebryx* of the Hamilton group.

117. *O demus* Hall

118. *Orthoceras fulgidum* Hall

Confined to the Ithaca beds.

119. *Orthoceras leander* Hall

Also in the Chemung

120. *O. pacutor* Hall

Probably an immigrant from the Naples fauna. All these smooth forms are probably derived from Hamilton species, but precise relationships can not be determined.

121. *O. pertextum* Hall

An annulated form with distinctive surface markings; confined to the Ithaca; derivation not known.

The eastern Ithaca Phase

The faunal characteristics of the eastern Ithaca beds are obtained from the list of species given by Dr. John M. Clarke for Chenango and Cortland counties[27] and by Prosser for these beds from 78 localities dis-

[27] John M. Clarke: Annual Report of the State Geologist of New York for 1895.

tributed between the Chenango River and the Schoharie Valley on the north and the Port Jervis region on the south. In Table III, pages 452-459, these species are listed first for Chenango and Cortland counties according to Clarke, and then under six headings which represent the localities from west to east studied by Prosser, as follows:

1. Chenango Valley.
2. Unadilla Valley.
3. Susquehanna Valley.
4. Charlotte Valley.
5. Schoharie Valley.
6. Green County and Port Jervis region.

In each of these six groups, the first column shows the number of localities from which the species has been reported, and the second the summarized abundance for that group of localities. In the next five columns the occurrence in other formations is given, while the last group of columns represents an analysis as to the origin of the various elements of the fauna.

It should be noted that the Ithaca fauna ranges through several hundred feet of strata in the western sections, but becomes more and more restricted as we approach the Schoharie region, where the continental Oneonta beds appear at successive lower horizons.

On the east side of the Schoharie Valley, in Moheganter Hill, the Ithaca is scarcely represented by fossiliferous beds, there being a few strata with fragments of fossils of this horizon, above the coarse sandstones referred to the Sherburne and below the red beds of the Oneonta, which latter type of sedimentation here begins lower than it does farther west, as demonstrated by Prosser. Even on the west side of the Schoharie Valley the Ithaca is better developed, covering the high part of the plateau to the south of Panther Creek and west of the Schoharie River, in the southern part of Fulton township. Except for the abundant representation of *Spirifer mesistrialis* Hall, the fauna is essentially a Hamilton fauna. A remnant of the Ithaca fauna of a pure Hamilton aspect is found in the Catskill Creek section in Green County, where the following species occur 470 feet above the first appearance of the red beds of the Oneonta type (Prosser, p. 270):

1. *Spirifer mucronatus* (small)[28]	(c)
2. *Schuchertella chemungensis arctostriata*	(a)
3. *Tropidoleptus carinatus*	(r)
4. *Homalonotus dekayi*	(rr)

[28] Probably *Mucronatus posterus*.

5. *Nuculites triqueter*	(rr)
6. *Chonetes scitula*	(c)
7. *Palæoneilo constricta*	(rr)

As we pass southward the base of the continental series descends, until in the Kingston region the continental sediments comprise more than one-third of the Hamilton series. This will be more fully discussed below.

Table III.—Ithaca Fauna from Chenango Valley Eastward

	Chenango and Cortland Counties (Clarke)	1 Chenango Valley: Number of localities	2 Chenango Valley: Abundance	3 Unadilla Valley: Number of localities	4 Unadilla Valley: Abundance	5 Susquehanna Valley: Number of localities	6 Susquehanna Valley: Abundance	7 Charlotte Valley: Number of localities	8 Charlotte Valley: Abundance	9 Schoharie Valley: Number of localities	10 Schoharie Valley: Abundance	11 Green County and Port Jervis: Number of localities	12 Green County and Port Jervis: Abundance	13 Western Ithaca	14 Western Sherburne	15 Eastern Sherburne	16 Hamilton	17 Chemung	18 Ithaca immigrants	19 Naples immigrants	20 Chemung not in Western Ithaca
Anthozoa																					
1. *Anlopara annectans* Clarke	x																			x	
2. *Cladochonus* sp.						1	rr														
Bryozoa																					
‡ 2. *Cystodictya gilberti* Meek	x																x†				
Brachiopoda																					
* 1. *Ambocoelia umbonata* Con.	x	1	r							1	rr			x	x	x	x	x			
2. *Athyris spiriferoides* (Eaton)	x									2	rc						x				
* 3. *Atrypa reticularis* Linne	x	5	c	3	rr									x		x	x	x			
4. *Camarotoechia congregata* Hall	x																x				
5. *Camarotoechia contracta* Hall								1	r					x				x	x		
*† 6. *C. eximia* Hall				5+2	rc	9	rc	1	c	2	c	1	rr	x	x			x	x		
*† 7. *C. stephani* Hall		1	c	3	c	3	c	1	rr	1+2	c			x		?		x	x		
8. *C.* sp.						2	rr	1	rr	1	r	1	rr								
9. *Chonetes coronata* Con.								1	r	1	r					x	x				
10. *C. deflecta* (Conr.)	x																x				
11. *C. lepida* Hall	x					1?	r			1	r	1	rr	x	x	x	x	x			
12. *C. mucronata* Hall										1?	rr					x	x				
*†13. *C. scitula* Hall	x	3+1	c	5	c	6	rc					1	c	x			x	x			
†14. *C. setigera* Hall		4	c	4	c	6	rc	1	r	2	c	2	rr			x	x	x			
15. *C.* sp.						1	rr														
16. *Crania* sp.												1?	rr								

*17. *Cyrtina hamiltonense* Hall	x	3+1	rr	2	rc	1	rr	—	—	—	—	1	rr	x	x	x	x	—	—	—	
‡18. *C. cf. curvilineata* Hall	x	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	xt	—	—	—	—
19. *Eunella lincklæni* Hall	—	—	—	—	—	—	—	—	—	1	r	—	—	—	—	x	x	—	—	—	—
20. *Leptaena rhomboidalis*	x	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	x	x	—	—	x
21. *Lingula* sp	—	—	—	—	—	—	—	—	—	1	rr	—	—	—	—	—	—	—	—	—	—
22. *Lingula ligea* var. Hall	x	—	—	—	—	—	—	—	—	—	—	—	—	x	—	—	x	—	—	x	—
*†23. *Liorhynchus mesacostalis* Hall	x	7	c	5+1	r	—	—	—	—	1?	rr	1	rr	x	x	x	—	x	x	—	—
24. *L.* sp	—	—	—	—	—	—	—	—	—	1	c	1	rr	—	—	—	—	—	—	—	—
25. *Orbiculoidea* (*lodiensis*) *media* Hall	—	—	—	—	—	—	—	—	—	1?	rr	—	—	—	—	—	x	x	—	—	—
26. *O. neglecta* Hall	—	—	—	—	—	1	rr	—	—	1?	rr	—	—	x	—	—	—	x	x	—	—
27. *O.* sp	—	—	—	—	—	—	—	—	—	2	rr	—	—	—	—	—	—	—	—	—	—
28. *Pholidops hamiltoniæ* Hall	x	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	x	—	—	—	—
29. *Productella dumosa* Hall	—	1?	c	—	—	—	—	—	—	—	—	—	—	—	—	—	x	—	—	—	—
*30. *Productella speciosa* Hall	—	1?	rr	1+1	r	1	r	—	—	—	—	—	—	x	—	—	—	x	x	—	—
31. *P. spinulicosta* Hall	x	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	x	—	—	—	—
32. *P.* sp	—	1	c	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
33. *Rhipidomella vanuxemi* Hall	x	1?	rr	—	—	—	—	—	—	1?	rr	—	—	—	—	—	x	—	—	—	—
‡34. *Schizophoria impressa* Hall	x	—	—	—	—	—	—	—	—	—	—	—	—	x	—	—	—	xt	x	—	—
35. *Schuchertella chemungensis* (Conrad)	—	1	r	1	a	—	—	—	—	2	rr	—	—	—	—	—	—	x	—	—	x
36. *S. chemungensis arctostriata* Hall	x	—	—	—	—	—	—	—	—	—	—	1	a	—	—	x	x	—	—	—	—
37. *Spirifer audaculus* Con	x	1	r	—	—	—	—	—	—	—	—	—	—	—	—	x	x	—	—	—	—
‡38. *S. asper* Hall	x	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	x	—	—	—	—
39. *S.* (*Reticularia*) *fimbriata* (Conrad)	—	1?	r	—	—	—	—	—	—	1	rr	—	—	x	—	x	x	x	—	—	—
40. *S. granulosus* Con	—	1+1	rr	1?	rr	—	—	—	—	1	r	—	—	—	—	x	x	—	—	—	—
41. *S. laevis* Hall	x	—	—	—	—	—	—	—	—	—	—	—	—	x	x	—	—	x	x	—	—
42. *S. medialis* Hall	—	—	—	—	—	—	—	1	r	—	—	—	—	—	—	—	x	—	—	—	—
43. *S. mesicostalis* Hall	—	1	rr	—	—	1+4	c	—	—	—	—	—	—	—	—	—	—	x	—	—	x
*†44. *S. mesastrialis* Hall [28]	x	2+1	r	8	c	12	c	4+1	c	13+3	c	2	rc	x	—	?	—	x	x	—	—
†45. *S. mucronatus* (Con.)	x	6	c	3+1	c	6	rc	4	r	8+4	rc	3	a	—	—	x	x	—	—	—	—
*46. *S. mucronatus posterus* Hall and Clarke	x	1	r	2	rc	—	—	—	—	—	—	—	—	x	—	x	—	—	x	—	—
47. *S. sculptilis* Hall	x	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	x	—	—	—	—
48. *S. tullius* Hall	x	—	—	—	—	—	—	1	r	3	c	—	—	—	—	x	x	—	—	—	—
49. *S.* sp	—	1	rr	—	—	2	r	—	—	2	r	—	—	—	—	—	—	—	—	—	—
50. *Strophalosia truncata* Hall	x	—	—	—	—	1?	rr	—	—	—	—	—	—	x	—	x	x	—	—	—	—
51. *S.* sp	—	—	—	—	—	2	rr	—	—	—	—	—	—	—	—	—	—	—	—	—	—
52. *Stropheodonta demissa* Con	—	—	—	1	rr	—	—	—	—	—	—	—	—	?	—	—	x	—	—	—	—
*53. *S.* (*Leptostrophia*) *mucronata* Con	x	1?	r	—	—	—	—	—	—	—	—	—	—	x	x	—	—	x	x	—	—
54. *S.* (*Leptostrophia*) *perplana* Con	x	2?	rr	—	—	—	—	—	—	—	—	—	—	—	—	x	x	—	—	—	—
†55. *Tropidoleptus carinatus* Hall	x	4	c	6	c	8	rc	3	rr	12	rc	3	rc	—	—	x	x	x	—	—	—

28 Probably *S. mucronatus posterus*.

Table III—continued

Pelecypoda	Chenango and Cortland Counties (Clarke)	1 Chenango Valley: Number of localities	2 Chenango Valley: Abundance	3 Unadilla Valley: Number of localities	4 Unadilla Valley: Abundance	5 Susquehanna Valley: Number of localities	6 Susquehanna Valley: Abundance	7 Charlotte Valley: Number of localities	8 Charlotte Valley: Abundance	9 Schoharie Valley: Number of localities	10 Schoharie Valley: Abundance	11 Green County and Port Jervis: Number of localities	12 Green County and Port Jervis: Abundance	13 Western Ithaca	14 Western Sherburne	15 Eastern Sherburne	16 Hamilton	17 Chemung	18 Ithaca immigrants	19 Naples immigrants	20 Chemung not in Western Ithaca
*† 1. *Actinopteria boydi* Con.	x	1	rr	2	c			4	c	5+1	c	2+1	rc	x		x	x				
2. *A. decussata* Hall										1	rr						x				
3. *A. eta* Hall ?	x			1?	r													x			x
4. *A. perstrialis* Hall	x													x	x				x		
5. *A. theta* Hall ?				1	r	1?	rr											x			x
6. *A. zeta* Hall ?	x			1?	r													x			x
7. *A.* sp.				2	rr	1	rr			1+1	r										
8. *Cimitaria recurva* Con.		2	r			1?	rr			1	rr						x				
9. *C. elongata*	x																x				
10. *Edmondia subovata* Hall						1?	r							x				x	x		
11. *Glossites depressus* Hall		1	rr							1?	rr	1?	rr	x	x			x	x		
12. *Glyptodesma erectum* Con.						1	rr	1	rr	2	c					x	x				
13. *Goniophora carinata* (Hall)		1?	rr			3	rr			4	rr	1	rr				x				
14. *G. hamiltonensis* (Hall)	x			1	rr	1?	rr	1?	rr	3+2	rc			x		x	x				
15. *G. rugosa* Con.	x									1	rr						x				
16. *G. subrecta* Hall	x																	x			
17. *G.* sp.						2	rr			1	rr										
18. *Grammysia (Sphenomya) arcuata* Con.	x							1	rr	1	rr						x				
19. *G. bisulcata* Conrad	x			1	rr					2	r					x	x				
20. *G. constricta* Hall	x					1	rr										x				
21. *G. (Sphenomya) cuneata* Hall								1?	rr	1+1	rr						x				
22. *G. elliptica* Hall	x			2?	rr	1	rr			1?	rr							x			x
23. *G. globosa* Hall										1	rr						x				
24. *G. magna* Hall	x					1	rr										x				
25. *G. nodocostata* Hall						2	rr										x				
26. *G. obsoleta* Hall										1?	rr						x				
*27. *G. subarcuata* Hall				1	rr					2	rr	1?	rr	x	x			x	x		
28. *G.* sp.						1	rr	1	rr												
29. *Leda (Nuculana) brevirostris* Hall	x									1	rr						x				

29. *Leda diversa* Hall	x	1	r	—	—	1	r	—	—	2	rr	1	r	x	x	x	x	—	—	—	—
30. *Leptodesma rogersi* Hall	x	1+1	r	1	r	2+1	rc	1+1	r	2+1	rc	—	—	—	—	—	x	—	—	—	—
31. *L.* sp	—	—	—	—	—	2+1	rr	—	—	—	—	—	—	—	—	—	—	—	—	—	—
32. *Liopteria bigsbyi* Hall	—	—	—	—	—	—	—	—	—	1	r	—	—	—	—	—	x	—	—	—	—
33. *L. greeni* Hall	x	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	x	—	—	—	—
34. *L. dekayi* Hall	—	—	—	—	—	—	—	—	—	3	rr	—	—	—	—	x	x	—	—	—	—
35. *L. laevis* Hall	x	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	x	—	—	—	—
36. *L.* sp	—	—	—	—	—	1	rr	—	—	1	r	—	—	—	—	—	—	—	—	—	—
37. *L. sayi* Hall	x	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	x	—	—	—	—
38. *Lunulicardium ornatum* Hall	—	—	—	—	—	1?	rr	—	—	—	—	—	—	—	—	—	—	—	—	x	—
39. *Macrodon hamiltoniae* Hall	—	—	—	—	—	—	—	1?	r	1	rr	—	—	x	—	—	x	—	—	—	—
*40. *Microdon (Cypricardella) bellistriata* C	x	1·1	r	—	—	2	rr	1	rr	1+1	rr	—	—	—	—	—	x	—	—	—	—
41. *M. complanatus* Hall	—	—	—	—	—	—	—	1	rr	2	rr	—	—	x	—	—	x	—	—	—	—
†42. *M. gregarius* Hall	x	1?	rr	—	—	1+1	rr	4	c	4+1	rr	2+1	c	x	—	x	x	—	—	—	—
43. *M. tenuistriatus* Hall	—	—	—	—	—	3	r	—	—	2	r	—	—	x	—	x	x	—	—	—	—
44. *Modiella pygmæa* Hall	x	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	x	—	—	—	—
45. *Modiomorpha concentrica* Hall	x	1	rr	—	—	2	rr	—	—	1	rr	—	—	x	—	—	x	—	—	—	—
46. *M. mytiloides* (Con.)	x	1	rr	—	—	1+1	rr	1+1	rr	1	rr	1?	rr	—	—	—	x	—	—	—	—
47. *M. subalata* (Con.)	x	—	—	1?	r	—	—	—	—	—	—	1?	rr	x	x	x	x	—	—	—	—
*48. *M. subalata chemungensis* Hall	—	—	—	2	rr	2	r	—	—	2	rr	1?	rr	x	x	x	—	x	x	—	—
49. *M.* sp	—	1	rr	—	—	1	r	1	rr	1	r	—	—	—	—	—	—	—	—	—	—
50. *Nucula bellistriata* Hall	—	—	—	2	r	2?	c	1?	r	1	rr	—	—	—	—	x	x	—	—	—	—
51. *N. bellistriata* var	—	—	—	—	—	2	rc	—	—	—	—	—	—	—	—	—	—	—	—	—	—
52. *N. corbuliformis* Hall	x	1?	r	3	r	1?	rr	1+1	rr	1	rr	—	—	x	—	x	x	x	—	—	—
53. *N. cuneiformis* Conrad	—	—	—	1	rr	2	rr	—	—	2?	rr	—	—	—	—	—	x	—	—	—	—
54. *N. lirata* Conrad	x	1	r	—	—	—	—	—	—	—	—	—	—	—	—	—	x	—	—	—	—

Table III—continued

Pelecypoda—continued	Chenango and Cortland Counties (Clarke)	1 Chenango Valley: Number of localities	2 Chenango Valley: Abundance	3 Unadilla Valley: Number of localities	4 Unadilla Valley: Abundance	5 Susquehanna Valley: Number of localities	6 Susquehanna Valley: Abundance	7 Charlotte Valley: Number of localities	8 Charlotte Valley: Abundance	9 Schoharie Valley: Number of localities	10 Schoharie Valley: Abundance	11 Green County and Port Jervis: Number of localities	12 Green County and Port Jervis: Abundance	13 Western Ithaca	14 Western Sherburne	15 Eastern Sherburne	16 Hamilton	17 Chemung	18 Ithaca immigrants	19 Naples immigrants	20 Chemung not in Western Ithaca
55. *N. oblongatus* Conrad	—	—	—	—	—	4 + 2	rc	1	rr	2 + 1	rr	—	—	—	—	x	x	—	—	—	—
56. *N. triqueter* Conrad	—	—	—	—	—	1	rr	—	—	1	rr	1	rr	x	—	x	x	—	—	—	—
57. *Nyassa arguta* Hall	—	—	—	—	—	—	—	—	—	1	c	—	—	—	—	x	x	—	—	—	—
58. *Orthonota carinata* Conrad	—	—	—	—	—	—	—	—	—	—	—	1	rr	—	—	—	x	—	—	—	—
59. *O. parvula* Hall	—	—	—	—	—	1	rr	—	—	—	—	—	—	—	—	?	x	—	—	—	—
60. *O. undulata* Conrad	—	—	—	—	—	1	rr	—	—	3	rc	—	—	—	—	x	x	—	—	—	—
61. *Palæoneilo brevis* Hall	x	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	x	—	—	—
*62. *Palæoneilo constricta* Con.	x	2	rr	2	rr	—	—	—	—	2 + 1	rr	2	rr	x	—	x	x	x	—	—	—
63. *P. constricta flexuosa* Hall	—	—	—	—	—	—	—	—	—	1	rr	—	—	x	x	—	x	—	—	—	—
†64. *P. emarginata* Con.	x	3	rr	2	rr	1	rr	2	rr	1 + 1	rr	1	rr	?	—	—	x	—	—	—	—
65. *P. emargniata var*	—	—	—	—	—	—	—	2	r	2	r	—	—	—	—	—	—	—	—	—	—
66. *P. fecunda* Hall	x	2	rr	—	—	—	—	—	—	—	—	—	—	—	—	—	x	—	—	—	—
67. *P. maxima* Con.	x	1	c	1	rr	5 + 1	rr	1	rr	1	c	—	—	—	—	—	x	—	—	—	—
68. *P. muta* Hall	—	1	r	—	—	2?	r	1	rr	—	—	—	—	—	—	—	x	—	—	—	—
69. *P. plana* Hall	—	—	—	—	—	—	—	2	rr	2?	rr	1	rr	x	—	—	x	—	—	—	—
70. *P.* sp.	—	—	—	—	—	2	rr	—	—	1	rr	—	—	—	—	—	—	—	—	—	—
†71. *Paracyclas lirata* Con.	x	5	c	3	rr	10	rc	1	r	—	—	3	rc	—	—	x	x	—	—	—	—
72. *P. tenuis* Hall	—	—	—	—	—	—	—	—	—	1	rr	—	—	—	—	—	x	—	—	—	—
73. *Pholadella radiata* (Con.)	—	—	—	—	—	—	—	—	—	1	c	—	—	x	—	—	x	—	—	—	—
74. *Prothyris lanceolata* Hall	—	—	—	—	—	2	rr	—	—	—	—	—	—	—	—	—	x	—	—	—	—

75. *Pterinopecten suborbicularis* Hall	—	—	—	1?	rr	—	—	—	—	1?	c	—	—	x	—	—	—	x	x	—	—
76. *P. vertumnus* Hall	—	—	—	—	—	—	—	—	—	1?	rr	—	—	—	—	x	x	—	—	—	—
77. *P.* sp	—	—	—	—	—	—	—	—	—	2	rr	—	—	—	—	—	—	—	—	—	—
78. *Pterochaenia fragilis* Hall	—	—	—	—	—	—	—	—	—	1	rr	—	—	x	x	—	—	—	—	x	—
79. *Schizodus (Cythorodon) appressus* (Conrad)	x	—	—	—	—	—	—	—	—	2 + 1	r	—	—	—	—	x	x	—	—	—	—
80. *S. (C.) ellipticus* Hall	—	—	—	—	—	—	—	—	—	1?	r	—	—	—	—	—	x	—	—	—	—
81. *S.* sp	—	—	—	—	—	—	—	—	—	1?	rr	—	—	—	—	—	—	—	—	—	—
82. *Solen (Palaeosolen) siliquoidea* Hall	—	—	—	—	—	—	—	—	—	1 + 1	rr	—	—	—	—	—	x	—	—	—	—
83. *Sphenomya cuneata* Hall	x	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	x	—	—	—	—
84. *Sphenotus contractus* Hall	x	—	—	—	—	1?	rr	—	—	—	—	—	—	—	—	—	—	x	—	—	—
85. *S. cuneatus* Con	—	—	—	—	—	—	—	—	—	3 + 1	c	—	—	—	—	—	x	—	—	—	—
86. *S. solenoides* Hall	—	—	—	—	—	—	—	—	—	1?	rr	—	—	—	—	—	x	—	—	—	—
87. *S. truncatus* (Con.)	—	—	—	—	—	—	—	—	—	3 + 1	rc	—	—	—	—	x	x	—	—	—	—
88. *Tellinopsis subemarginata* C	—	—	—	1	rr	2	rr	—	—	—	—	—	—	—	—	x	x	—	—	—	—

Gastropoda

1. *Bellerophon acutilirata* Hall	—	—	—	—	—	—	—	—	—	1 + 1	r	—	—	—	—	—	x	—	—	—	—
2. *B. patulus* Hall	x	—	—	—	—	—	—	—	—	2	rc	—	—	—	—	—	x	—	—	—	—
3. *B. rudis* Hall	—	—	—	—	—	1?	rr	—	—	—	—	—	—	—	—	—	x	—	—	—	—
4. *B.* sp	—	—	—	—	—	1	rr	—	—	1	rr	—	—	—	—	—	—	—	—	—	—
5. *Cyrtolites (Cyrtonella) pileolus* Hall	—	—	—	—	—	—	—	—	—	1 + 1	rr	—	—	—	—	—	x	—	—	—	—
*6. *Pleurotomaria capillaria* Con	—	—	—	1	c	—	—	—	—	—	—	—	—	x	x	—	x	—	—	—	—
7. *P. itys* Hall	x	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	x	—	—	—	—
8. *P. lucina* Hall	—	—	—	—	—	—	—	1	r	—	—	—	—	—	—	—	x	—	—	—	—

Table III—continued

	Chenango and Cortland Counties (Clarke)	1 Chenango Valley: Number of localities	2 Chenango Valley: Abundance	3 Unadilla Valley: Number of localities	4 Unadilla Valley: Abundance	5 Susquehanna Valley: Number of localities	6 Susquehanna Valley: Abundance	7 Charlotte Valley: Number of localities	8 Charlotte Valley: Abundance	9 Schoharie Valley: Number of localities	10 Schoharie Valley: Abundance	11 Green County and Port Jervis: Number of localities	12 Green County and Port Jervis: Abundance	13 Western Ithaca	14 Western Sherburne	15 Eastern Sherburne	16 Hamilton	17 Chemung	18 Ithaca immigrants	19 Naples immigrants	20 Chemung not in Western Ithaca
Gastropoda—continued																					
9. *P. rotalia* Hall				1?	c					1	rr						x				
10. *P. sulcomarginata* Conrad	x					3	rc										x				
11. *P.* cf. *trilix*	x																x				
12. *P.* sp.						2	r														
Pteropoda																					
1. *Coleolus aciculum* Hall				1?	r					1	rr			x	x					x	
2. *C. tenuicinctum* Hall						2	rc			1	rr					?	x				
3. *C.* sp.						4	rr														
4. *Conularia undulata* Hall	x																x				
5. *Hyolithes aclis* Hall	x									1	rr				x		x				
6. *H.* sp.						1	rr														
7. *Styliolina fissurella* Hall	x													x	x					x	
8. *Tentaculites attenuatus* Hall				1?	r	1?	r	1?	c								x				
9. *T. bellulus* Hall	x																x				
10. *T. spiculus* Hall	x									1	c			x				x	x		
11. *T.* sp.						5	rc			2	rc										
Cephalopoda																					
1. *Gephyroceras perlatum* (Hall)	x																			x	
2. *Manticoceras patersoni* (Hall)	x																			x	
3. *Orthoceras* sp.						3	rr														
4. *Tornoceras uniangulare* (Hall)	x													x			x			x	

Trilobita																					
1. *Dalmanites (Cryphaeus) boothi* Green	—	—	—	—	—	—	—	—	—	2	r	—	—	—	—	—	x	—	—	—	—
2. *Hamalonotus dekayi* Green	x	—	—	1	rr	2	rr	—	—	—	—	2	rr	—	—	x	x	—	—	—	—
3. *Phacops rana* Green	x	?	rr	2	r	—	—	1	rr	1	rr	—	—	x	—	—	x	—	—	—	—
Malacostraca																					
1. *Rhinocaris ? bipennis* Clarke	x	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	x	—
Crinoidea																					
1. Crinoid segments and stems	—	—	—	—	—	6	rc	1	r	2	r	—	—	—	—	—	—	—	—	—	—
2. *Melocrinus tricyclus* (Eaton)	x	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	x	—	—	—	—
3. *Poteriocrinus gregarinus* Williams	x	—	—	—	—	—	—	—	—	—	—	—	—	x	—	—	—	—	—	—	—
4. *Taxocrinus ithacaensis* Weller	x	—	—	—	—	—	—	—	—	—	—	—	—	x	—	—	—	—	—	—	—
Plantae																					
1. *Lepidodendron* sp.	—	—	—	—	—	—	—	—	—	1	rr	1	rr	—	—	—	—	—	—	—	—
2. *Psilophyton princeps* Dawson	—	—	—	—	—	—	—	—	—	1	c	1?	r	x	—	—	x	—	—	—	—
3. *Rhodia pinnata* Dawson	—	—	—	—	—	1?	r	—	—	—	—	—	—	—	—	x	x	—	—	—	—
4. Plant stems	—	—	—	—	—	1	c	—	—	1	r	—	—	—	—	—	—	—	—	—	—
Vertebrata																					
1. Fish teeth and plates	—	—	—	—	—	1	r	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Incerte sedes																					
1. *Spirophyton* sp.	—	2	rr	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

The 17 species starred in the foregoing table are given by Williams[29] as dominant species of the Ithaca fauna at Ithaca. Three others of that list do not occur in the eastern Ithaca. These are:

Paleoneilo filosa.
Cystodictya meeki.
Orthoceras bebryx var. *cayuga.*

The 12 species marked by a dagger (†) are considered by Williams the dominant types of the eastern extension of the Ithaca fauna. It will be observed that 6, or half of the number, are also dominant at Ithaca, the remaining 6 being typical Hamilton species. The double dagger (‡) indicates species of the Traverse fauna of Michigan and Iowa, also marked xt in Table III.

Where the numbers in the columns are double, as $\left\{\begin{matrix}2\\+\\1\end{matrix}\right\}$, or 2 + 1, the first, or upper, figure refers to the number specifically identified, the second, or lower, figure to the number doubtfully identified.

Table IV.—*Summary of Species of Ithaca Fauna of Chenango and Cortland Counties* (*Clarke's Lists*)

Classes.	Number of species.	Eastern Hamilton forms.	Traverse immigrants.	True Ithaca forms.	Late Ithaca or Chemung forms.	Naples immigrants.
Anthozoa	1	.....	.....	.....	.....	1
Bryozoa	1	.....	1	.....	.....	......
Brachiopoda	29	21	2	5	.....	1
Pelecypoda	37	29	.....	2	6	......
Gastropoda and Pteropoda	9	7	.....	1	.....	1
Cephalopoda	3	.....	.....	.....	.....	3
Crustacea	3	2	.....	.....	.....	1
Crinoidea	3	1?	.....	2	.....	......
Total	86	60	3	10	6	7
Percentage	100.	69.77	3.49	11.63	6.98	8.14

This summary shows the predominant Hamilton character of this fauna, nearly 70 per cent of the species being of this origin. Of the Ithaca forms, which include both of those Ithaca species which are found in the type region and the "late Ithaca," which have so far been found only in the Chemung, there are 18.61 per cent, or 16 species, as com-

[29] Bull. U. S. Geol. Survey, 210, p. 74.

TABLE V.—*Summary of Species of Ithaca Fauna from Chenango Valley eastward (Prosser's Stations)*

	Number of species listed.	Doubtful identification.	Not specifically identified.	Total to be subtracted.	Specifically identified.	Western Ithaca.	Western Sherburne.	Eastern Sherburne.	Hamilton.	Chemung.	Ithaca immigrants.	Naples immigrants.	Chemung not in Ithaca.	Iowa immigrants.	New forms.
Anthozoa	1	—	1	1	0	—	—	—	—	—	—	—	—	—	—
Brachiopoda	44	7	9	16	28	14 + 3	5 + 1	16 + 5	18 + 6	16 + 2	8 + 1	0	2	0	0
Pelecypoda	80	12	9	21	59	18 + 4	6 + 1	20 + 3	52 + 5	6 + 6	3 + 2	1 + 1	1 + 4	0	2
Gastropoda	10	1	2	3	7	1	1	0	7 + 1	0	0	0	0	0	0
Pteropoda	8	1	3	4	4	2	2	0 + 1	2 + 1	1	1	1	0	0	0
Cephalopoda	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0
Trilobitæ	3	0	0	0	3	1	0	1	3	0	0	0	0	0	0
Crinoidea	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0
Plantæ	4	1	2	3	1	1	0	0 + 1	1 + 1	0	0	0	0	0	0
Vertebrata	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0
Incertæ sedis	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0
Total	154	22	30	52	102	37 + 7	14 + 2	37 + 10	83 + 14	23 + 8	12 + 3	2 + 1	3 + 4	0	2

pared with 60 Hamilton species. Of the remaining 10 forms, 3 are hold-overs from the Traverse fauna of the interior, and 7 are immigrants from the Naples fauna.

In the next table (V, page 461) the species from the eastern sections are analyzed from Prosser's determinations.

An inspection of this table will show that out of a total of 124 specifically identified forms, 97, or 78.23 per cent, including 22 doubtful forms, are Hamilton types, while 15, or 12.1 per cent, are immigrants from the Ithaca region, where the indigenous Portage fauna developed—that is, west of the Sheburne bar.

Of the 12 remaining species, 3 are immigrants from the Naples fauna, two are unnamed varieties of Hamilton species, and 7 (2 brachiopods and 5 pelecypods) are Chemung species, not yet recorded from the typical Ithaca fauna. Of these 4 pelecypods are, however, only doubtfully identified and the fifth, *Grammysia elliptica,* positively only from a single locality, while the two brachiopods, *Schuchertella chemungensis* and *Spirifer mesicostalis,*[30] both occur in the Ithaca of the Chenango Valley and may also be found in that of the type region.

It is thus a significant fact that the species not holding over from the Hamilton are practically all characteristic of the Ithaca fauna of the typical Ithaca region or are Naples immigrants, and we may therefore conclude that these species passed eastward across the former Sherburne barrier to commingle with the residual Hamilton types.

This ability to enter the eastern waters and live side by side with the unmodified Hamilton fauna, which was constantly replenished by new arrivals from the Atlantic, clearly show that the Sherburne bar was no longer an effective barrier, but that it became submerged early in Portage time.

In the following table the relationships of the western (typical), central (Chenango and Cortland counties), and eastern Ithaca faunas are shown, all the doubtfully identified species being excluded.

[30] The specimens identified by Prosser as *Spirifer mesicostalis* may all be forms of *S. mucronatus* var. *posterus,* especially as the identifications from the Susquehanna Valley are mostly questioned by Prosser.

TABLE VI.—*Composition and Relationships of Western (typical), Central, and Eastern Ithaca Faunas*

Species.	Ithaca of Ithaca region.		Ithaca of Chenango and Cortland counties (Clarke).		Ithaca east of Chenango Valley (Prosser).	
	Number of species.	Percentage.	Number of species.	Percentage.	Number of species.	Percentage.
Total number of species, excluding those doubtfully identified	107	100.00	86	100.0	102	100.0
Hamilton species	39	36.45	60	69.77	83	81.38
Naples species	9	8.40	7	8.14	2	1.96
Iowan species	3	2.80	3	3.49	0	0.00
New or Ithaca species..	56 [31]	52.35	10	11.63	12	11.76
New varieties of Hamilton species	.....	......	....	......	2	1.96
Chemung species, not recorded from Ithaca fauna	.....	......	6	6.98	3	2.94

This comparison very clearly shows that the Ithaca fauna west of the former Sherburne bar—that is, in the region of the ancestral home of the Ithaca fauna—is modified only to a moderate degree by the immigrant Hamilton fauna from the east (or the persistent Hamilton types within the Ithaca basin). The Hamilton element constitutes only 36.5 per cent of the whole of the Ithaca fauna in the type region, while nearly 52.5 per cent of the fauna are new types, developed *in situ* from the preceding Hamilton fauna. In the eastern region, however, the fauna of the Ithaca beds is still largely a Hamilton one, species of that type constituting 83 1/3 per cent of the whole,[32] while only 16 2/3 per cent are immigrant Ithaca and Naples species from the Ithaca region.[33] The central region is intermediate, showing about 70 per cent Hamilton and 18.6 per cent Ithaca.[34] An inspection of the larger table, III, will show that, with few, almost negligible, exceptions, the immigrants from the western area are confined to, or at least most common in, the more westerly portion of the eastern region—that is, that nearest the home of the Ithaca fauna. It is also apparent that, whereas in the Ithaca region nearly 8.5 per cent of the Ithaca fauna consists of Naples species and 2.8 per cent of Iowan species, the eastern Ithaca fauna has only about 2 per cent of its total

[31] This includes the 18 species which make their first appearance in the Sherburne or Lower Portage of the Ithaca region.

[32] Including the two new varieties of Hamilton species.

[33] This includes the three Chemung species not yet reported from the Ithaca, but probably occurring there.

[34] This includes the six Chemung species not yet recorded from the typical Ithaca.

derived from the Naples and none from the Iowan fauna. The central region is again essentially intermediate.

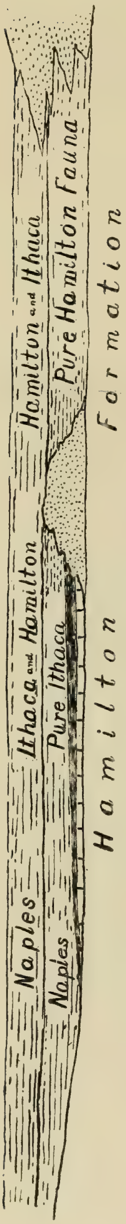

FIGURE 2.—*East and west Section across New York State*

Showing the faunas on opposite sides of the Sherburne Bar. The pure Ithaca is the fauna of the Lower Portage of the Ithaca region, developed from the Hamilton, which remained pure east of the bar. After the submergence of the bar Hamilton species were added to the pure Ithaca, forming the typical Ithaca fauna. Ithaca species were added to the Hamilton on the east, forming the "Eastern Ithaca Fauna."

PALEOGEOGRAPHIC CONCLUSIONS DRAWN FROM THE FAUNAL DISTRIBUTION

We may now attempt to outline the sequence of events in North America during Portage time as indicated by the faunas and sediments (see section, figure 2). The Hamilton period came to a close with the contraction of the North American epeiric sea and its division into three distinct basins, separated in part at least by land barriers. Before the separation was complete, however, members of the Iowan Traverse fauna were temporarily enabled to enter New York district. This gave us the leading elements of the Tully fauna, such as *Hypothyris cuboides, Pugnax pugnus, Schizophoria tulliensis, etcetera,* which continued to flourish during the period of deposition of the Tully limestone. That isolation of the central New York area was effected soon after the incursion of the western fauna is shown by the fact that the residual Hamilton fauna began to undergo the modification which eventually led to the Ithaca fauna. This separation was effected on the east by the Sherburne bar, which extended from the old land of Atlantica, in the north, southward through Pennsylvania, possibly as far as the Harpers Ferry region, cutting off an eastern arm of the Atlantic from the central basin. In this eastern arm the Hamilton fauna continued to flourish in its purity, though much restricted as to numbers of species on account of the less favorable facies of the sea bottom. That the fauna nevertheless remained true to type can only be explained by the assumption of continued connection with the center of distribution of the Hamilton fauna. This center

appears to have been in the Atlantic of that day, and the connection could only have been in the Saint Lawrence region, since the facies of the early Upper Devonic deposits to the south, in Maryland and Virginia, changes to black muds, which indicates estuarine conditions, and the dwarfed fauna of which indicates low salinity of the waters. These same estuarine muds which embraced the lower end of the Sherburne Bar seem to have been instrumental in preventing the Hamilton fauna from migrating around the lower end of that bar into the central New York basin. The relation of the bar and the currents which distributed the muds in the estuary seem to have been such as to cause the chief mass of these muds to be spread to the west of the Sherburne Bar. Here they constitute the Genesee, West River, and Middlesex shales, all of which thin away westward and northward from south central New York.

It is quite clear that the changes which brought about the separation of the central New York and eastern basin by the Sherburne Bar, and which inaugurated the deposition of the black muds on the south and the more or less oxidized continental Oneonta sands and muds on the western slopes of Appalachia, also resulted in the separation of the Iowan and New York areas, but only after the final immigration of the Cuboides fauna. From Buffalo westward through Ontario, Michigan, Ohio, Indiana, Illinois, Wisconsin, and Iowa, as well as throughout most of the Rocky Mountain region, dry land conditions came into existence after the deposition of the Hamilton Traverse formation; for everywhere we find the Hamilton-Traverse or, in its absence, the older formations succeeded by an erosion interval, there being everywhere a marked disconformity between the Middle and Upper Devonic beds. This disconformity probably extends to the shores of James Bay, where in the Abitibi River Savage and Van Tuyl found shales with a Chemung fauna (*Liorhynchus mesacostalis* and *L. globuliforme*) resting upon Traverse beds.[35] It is quite probable, however, that in the far northwestern region (northwest Canada and Colorado) the deposition was continuous from Middle into Upper Devonic time, and it was here that the Traverse types largely persisted into the Upper Devonic.

In the central New York region, deposition after the separation of the basins began with the Tully limestones. This lime mud, as I have elsewhere shown,[36] was probably derived from a series of reefs which existed north of the line of present-day outcrop of the limestone and which have

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[35] Communication to the Geological Society of America, Albany meeting, December, 1916.

[36] Stratigraphic relationships of the Tully limestone and the Genesee shale in eastern North America. Bull. Geol. Soc. Am., vol. 28, 1917, pp. 945-958.

been entirely removed by the long post-Paleozoic erosion. The Tully sea was limited on the southwest by lowlands bordered by stagnant pools, in which the fauna became dwarfed. This produced the well known pyrite layer of the Tully, which can be traced from the Genesee River to Erie County. The fossils in this layer are on the average only one-fifth the size of the normal Tully or Hamilton species. On the east the Tully Sea was limited by the Sherburne Bar, and on the south by the encroaching estuarine muds of the Genesee, which progressively overlapped the Tully northward. (See the map on page 955 of volume 28 of the Bulletin of the Geological Society of America.)

The Tully fauna inaugurated the local modification of that remnant of the Hamilton fauna which was isolated by the formation of the Sherburne Bar and the elevation which cut off the Traverse fauna from the west. Not all forms became modified at first, since the condition of deposition and the facies of the sea bottom remained favorable; but we can trace the slow modification of this fauna into the Ithaca fauna, which developed under the influence of complete isolation and separation from the center of migration of the Hamilton fauna. Subsequently, indeed, this fauna became an integral part of the highest Devonic or Chemung fauna, as was long ago pointed out by Dr. J. M. Clarke.

The Sherburne sandstone, which succeeds the Tully in the Ithaca region and westward, carries chiefly this modified fauna, though 36 per cent of the species still represent Hamilton types. The descendants of the Iowan fauna likewise continue into the Sherburne and even the Ithaca periods. With the close of the Tully deposition, however, the pelagic Naples fauna entered the New York province and continued during the whole of Portage time in the more westerly area. This fauna could only have entered the New York province from the north, where, in the Petchoraland, on the other side of the North Polar region, it is likewise found. It could not have reached New York from the northwest, as there the very different Upper Devonic Iowan fauna existed, some members of which entered the New York province, as we have seen, at the beginning of Upper Devonic time, and remained as a part of the Tully and the succeeding Ithaca fauna.* The Iowan fauna came again into the New York area, and in greater force, at the end of Portage time, where we find it well developed in the limestone lentils of the High Point sandstone of central New York, as described by Clarke. The Naples fauna could not have entered the New York province from the east, for there the Sherburne barrier for a time shut out all im-

* Kindle has recently reported the Naples fauna from the Mackenzie River region, which indicates a westward spreading of this fauna in late Upper Devonic time.

migrants, while beyond this barrier was, as we have seen, the persistent Hamilton fauna which subsequently entered the New York province to constitute the conservative element of the Ithaca fauna. On the south were the extensive estuaries in which the black Ohio and Genesee muds were being deposited, their depauperate and dwarfed faunas indicating much dilution of the salt waters by the inpouring of rivers from the south. These black muds can be traced continuously from Maryland to Iowa, and as they are followed southward, or up the lateral margins of the ancient lagoons, they are found to pass into similar, though mostly undisturbed, terrigenous sands of Kinderhook or younger age.[37]

There is thus no possibility of deriving the Naples fauna from the south, for here was a continuous land-mass. It follows that the only available path of entry is the northern one, which, so far as our knowledge of the formation is concerned, satisfies all requirements. True, the Naples fauna has not yet been reported from Arctic America; but since this is the only possible path of entry, and since the fauna is found in Arctic Europe, we may confidently predict that, if fossiliferous Upper Devonic formations are preserved in our arctic region, they will be found to contain the Naples fauna.

It is of importance to recall that the Hamilton fauna continued in that portion of the Portage Sea which lay to the east of the Sherburne Bar, or approximately in that portion of New York State now comprising Otsego, Schoharie, Delaware, and Sullivan counties, on the south and parts of Montgomery, Fulton, and Saratoga counties and the Champlain Valley on the north. Thence the connection with the Atlantic was probably along the general line of the Saint Lawrence, though the Gaspé region of today was the site of continental sedimentation, as was the western margin of Appalachia farther south. Southward this arm of the Atlantic covered the region now included in the eastern counties of Pennsylvania and that portion of New Jersey lying west of the Skunnemunk-Green Pond inlier of Paleozoics. The region of this inlier was the site of lagoons in which the material of the Bellvale flags accumulated. The section at Port Jervis shows that that region lay within the confines of the embayment here outlined. How far south into eastern Maryland this embayment extended can not be determined, because the later Paleozoic rocks have been wholly removed from that region by Post-Paleozoic erosion. The preserved Devonic rocks of Maryland all belong to the basin west of the Sherburne Bar. In any case, as before stated,

[37] A. W. Grabau: Types of sedimentary overlap. Bull. Geol. Soc. Am., vol. 17, pp. 567-636 [593 et seq.].

the bar extended into the region of the estuary into which the Genesee muds were washed, and this probably closed the embayment on the south and prevented the persistent Hamilton fauna from migrating around the lower end of the bar and so reentering the central New York region.

The eastern shore of this arm of the Atlantic from Green Pond Mountain northward was the site of the great Catskill delta or alluvial deposit, which had begun to form even before the Hamilton period had come to an end, as will be more fully detailed later.

When the Sherburne Bar became submerged, later on, the Hamilton fauna which persisted in the eastern area passed into the central basin, there to commingle with the new indigenous fauna to constitute the typical Ithaca fauna. This now was limited on the west by the deposits which carry the pelagic Naples fauna, with which it interfingered, as shown by Clarke, and on the east by the encroaching continental fan of the Oneonta. The Portage was brought to a close by the exclusion of the Naples fauna from the north and by a reinvasion of the Iowan fauna from the west and the Atlantic Hamilton fauna from the east. By a combination of these faunas with the residual Ithaca fauna and renewed invasion of foreign types, the typical Chemung fauna came into existence.

The various provinces of this period have been given by Prof. J. M. Clarke in a map showing their distribution, as far as New York State is concerned (Memoir 6, New York State Museum, Plate B). This map indicates the maximum extent of the Oneonta as far as the region of the Sherburne Bar. Before this a part of the area colored for Oneonta was occupied by the residual Hamilton fauna and later by the mixed Hamilton-Ithaca fauna, as described in the preceding pages. Towards the end the Oneonta beds covered this entire region.

The Ashokan Formation or the so-called Sherburne Sandstone of the Helderbergs

Underlying the Oneonta formation of Ulster and Green counties is the principal flagstone-bearing formation of the Hudson River bluestone region. This is the Lower Flagstone series of Darton and it has a thickness of about 500 feet. In it are situated most of the important flagstone quarries of Ulster County, the most extensive and uniform deposits of the bluestone occurring in the lower part of the series. Higher beds often show characteristic cross-bedding of the torrential type, and irregularity of bedding, thinning and thickening of layers, channelings, and other current marks are common in certain portions. The series is unfos-

siliferous throughout, except for stipes of fernlike plants which abound on the surfaces of certain sandstone layers.

This formation was mapped by Prosser as the Sherburne sandstone of the Helderberg region and made continuous with the Sherburne of the type section. Of course, no continuous tracing of these beds from the Chenango Valley to the Helderberg was possible, and the correlation was made on the lithic similarity, the presence of similar plant stipes in both, and the fact that in Ulster, as in Chenango County, the rock of this character directly succeeded the fossiliferous Hamilton beds. Since rocks of somewhat similar character but with a modified Hamilton fauna succeeded the Hamilton of Otsego and Schoharie counties, it appeared that the Sherburne was a continuous formation lying at the base of the Upper Devonic of eastern New York and in part replacing the Tully limestone and Genesee shale of central New York. In my summary of the Ulster County section in the Schoharie Guide,[38] I have followed Prosser and used the name Sherburne for these unfossiliferous lower flags, and the same name was used by Berkey and by other writers on the rocks of the bluestone region. Continued study of these formations for a number of years has, however, convinced me that this correlation is not the correct one, and I have adopted for these beds the local name *Ashokan formation,* from the Ashokan district west of Kingston, New York, where the rock was quarried near, and for the use of the construction of, the Ashokan reservoir of the Catskill water system of New York City. I am satisfied that this formation is a continental phase of the Upper Hamilton and therefore beneath the base of the typical Sherburne sandstone. This is shown by the fact that in the Chenango Valley region the Hamilton, which underlies the Sherburne sandstone, and the Marcellus, which lies beneath it, have a combined thickness of 1,500 feet. At Schoharie, where the equivalent sandstones of the Sherburne carry an Ithaca fauna while still retaining the thickness of the typical Sherburne, the Hamilton is about 1,500 feet thick, while the Marcellus below it has a thickness of 180 feet, or about 1,680 feet for both formations. In Ulster County, on the other hand, the marine beds which underlie the Ashokan formation have a thickness of only about 400 or 500 feet. There are perhaps some 300 feet of shale between the exposed sandstones and shales and the Onondaga, a part of which must be classed as Marcellus. Farther north, at Clarksville, the Marcellus type of shale is well exposed, being 300 feet thick, while the more sandy Hamilton type is 490 feet and may have been 500 feet or more.

The passage of the marine into the non-marine beds of the Ulster

[38] N. Y. State Mus. Bull. 75, p. 303.

County Hamilton is seen in the sections west of Kingston (near West Hurley, etcetera), and it is evident that no stratigraphic break exists between the two. The fossiliferous Hamilton beds, therefore, can represent only the lower part of the Hamilton beds of the sections farther west, while the Ashokan represents its upper portion, which has a nonmarine character in the east. The marine beds are well exposed at Mount Marion, west of Saugerties, New York, and for them the name of *Mount Marion beds* is here proposed. The amended Ulster County succession of the Devonic is therefore as follows:

	Feet
Chemung series	
Catskill sandstone and conglomerate	1,725
Portage series	
Oneonta sandstone and shales	3,000
Hamilton series	
Ashokan shales and flags	500
Mt. Marion shales and sandstone	500
"Marcellus" shales	300
Onondaga series	
Onondaga limestone	75–85
Schoharie-Esopus	300
Oriskany	5–60
Port Ewen	0–150
Hiatus and disconformity	
Alsen[39] cherty limestones	20–50+
Becraft limestone	30–40
New Scotland	60–100
Coeymans	30–60
Base of Devonic (conformity)	
Manlius limestone of the Siluric.	

[39] This name is proposed for the cherty limestones which overlie the Becraft and contain a modified Becraft fauna. These beds are well shown in the hills above Alsen, at Becraft and Schoharie, and they are everywhere stratigraphically continuous with the Becraft. On Mount Becraft and at Schoharie, where they have heretofore been classed as Port Ewen, they are disconformably succeeded by the Oriskany sandstone. At Alsen the Port Ewen is likewise absent, but at Kingston and on the West Shore Railroad section near Port Ewen station the Port Ewen beds rest disconformably on the Alsen, of which 18 feet are shown on the West Shore section, while perhaps 10 feet have been removed, together with the Becraft, in the quarry which interrupts the section. The hiatus between the Alsen and Port Ewen or the Alsen and the Oriskany is marked by nearly 2,000 feet of calcareous deposition in the Gaspé region.

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PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY

PERMO-TRIASSIC OF NORTHWESTERN ARIZONA[1]

BY HERVEY W. SHIMER

(Presented before the Paleontological Society December 28, 1918)

CONTENTS

[1] Manuscript received by the Secretary of the Geological Society February 24, 1919.

Introduction

Four months' field work in New Mexico and Arizona, in 1906,[2] resulted in numerous geologic sections and fossil collections. Some of these results have been published.[3]

The present paper presents some Upper Permian and Lower Triassic ? sections, with their faunas as represented in our collections. The faunas are mainly from the upper Kaibab and lower Moenkopi formations.

Northern Arizona represents an old peneplained surface, developed with a slope to the south, which was raised into a plateau during the Pliocene. Since that time the softer Triassic ? shales have been largely eroded, leaving exposed the hard, siliceous Upper Permian (Kaibab) limestones. This erosion brought into relief old fault lines, and, with the aid of subsequent faulting along some old and many new lines, has produced the present topography. These strata, very nearly horizontal, have usually a gentle dip to the north; this is true from the southern edge of the plateau, the Mogollon Rim, to the Utah border where they dip beneath the later Mesozoic and Cenozoic beds.

Table of Formations

Triassic	Upper	Chinle	
		Shinarump conglomerate	Disconformity
	Lower	Moenkopi ?	Disconformity
Permian		Kaibab	
		Coconino	
		Supai (upper)	Disconformity
Pennsylvanian		Supai (middle and lower)	Disconformity
Mississippian (Lower)		Redwall	

[2] In a party under the most efficient leadership of Prof. Douglas W. Johnson, of Columbia University.

[3] The stratigraphy of the Mount Taylor region, New Mexico. Am. Jour. Sci., 4th ser., vol. 25, 1908, pp. 53-67.

The lithologic section of Walnut Canyon, Arizona, with relation to the cliff-dwellings of this and other regions of northwestern Arizona. Am. Anthropologist, vol. 12, 1910, pp. 237-249.

The small cave houses of Arizona. Science Conspectus, vol. 2, 1911, pp. 16-18.

Description of Sections

IN GENERAL

The following sections are described in order from those at the southeast to the ones at the northwest.

a. FROM THE MOGOLLONS TO FLAGSTAFF

As we traveled from the Basin Region (figure 1) northward up Oak Creek, the steep plateau escarpment gave excellent sections in the Permian shales and sandstones. The brick-red shales and sandstones of the Supai formation at the foot of the escarpment are overlain by the cross-bedded, gray Coconino sandstone at the plateau's edge, which in turn, farther to the north, dip under the thin, beveled, southern edge of the Kaibab limestone. In the plateau escarpment the upper fifty feet of the Supai are heavily cross-bedded, while the transition to the Coconino is an alternation of red and white sandstone beds. The surface of the plateau from the Rim to Flagstaff is at intervals covered with volcanic debris, concealing the underlying sediments. This dotting by recent volcanic cones and lava flows is characteristic of the entire plateau region of western New Mexico and northern Arizona. The surface sedimentary rocks, from a few miles north of the Rim to Flagstaff, are the yellowish to gray lower Kaibab limestone. Two miles directly south of Flagstaff, beside the trail, ledges of this limestone yielded

Cf. *Pustula nebraskensis* (Owen)	r
Composita subtilita (Hall)	r
Allorisma terminale Hall	c

b. WALNUT CANYON

Walnut Canyon is 8 miles southeast of Flagstaff and within the San Francisco Mountain Forest Reserve. The narrow canyon has been cut into a rolling upland to a depth of 370 feet. For a detailed lithologic section the reader is referred to the article in the *American Anthropologist* noted above. Briefly, from above downward, the section is as follows:

	Feet
1. Alternating yellowish to gray dolomites and limestones	285

The lower 150 feet contain the most conspicuous strata of the canyon: three prominent projecting ledges, with faces rounded by erosion, and beneath each a continuous cave zone. It is in these caves that the celebrated cliff-dwellings occur. From these 285 feet the following fossils were identified:

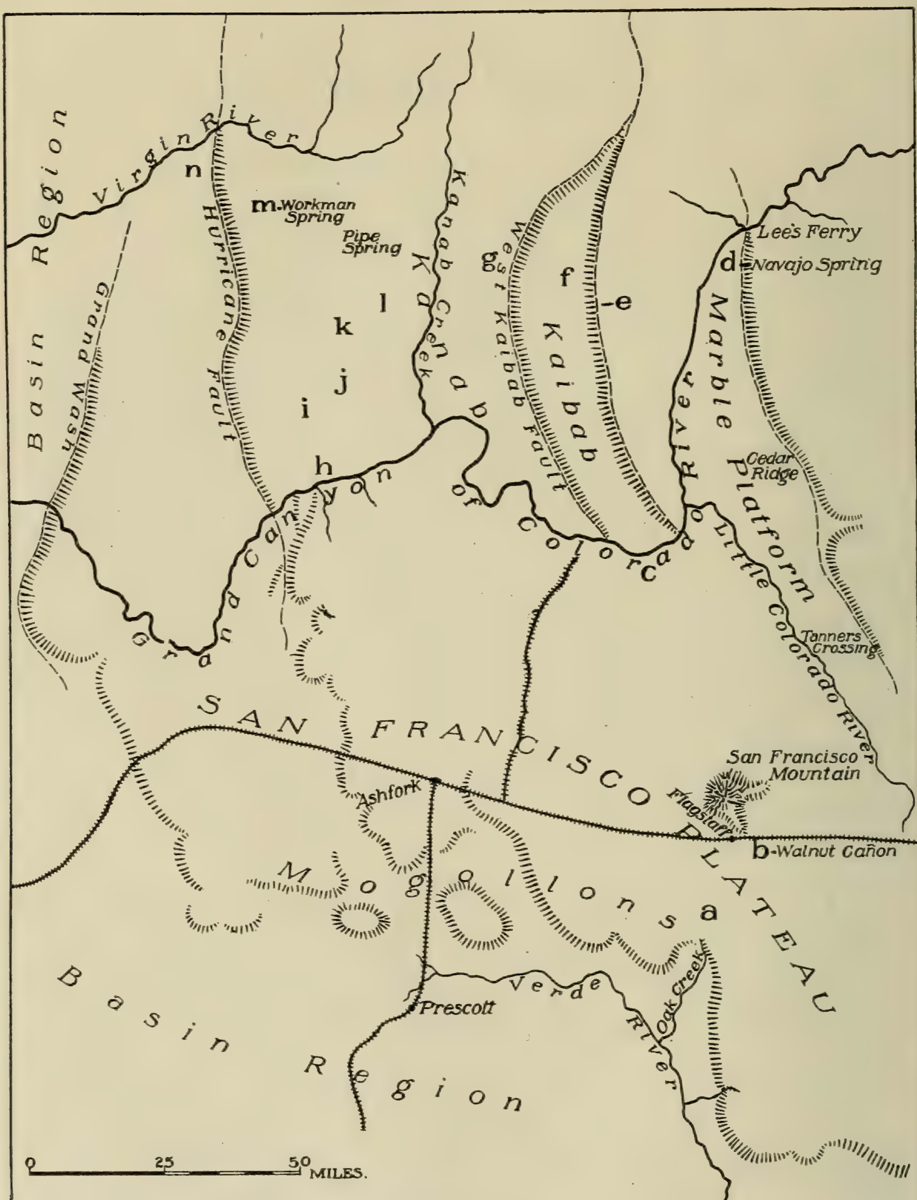

FIGURE 1.—*Sketch Map of Northwestern Arizona and Southern Utah*

The letters *a*, *b*, *c*, etcetera, refer to the geologic sections discussed (see table of contents)

Productus ivesi Newberry	c
Cf. *Pustula nebraskensis* (Owen)	r
Pinna sp.	R
Murchisonia terebra White ?	r

	Feet
2. Thin-bedded, brownish sandstone with a calcareous cement...........	10
3. Strongly cross-bedded, light gray sandstone........................	75

These beds, the Coconino sandstone, disconformably underlie the Kaibab limestone (localities 1 and 2).

c. GRAND CANYON OF THE COLORADO RIVER

As we traveled from Flagstaff around the western base of San Francisco Peak and northwestward to the Grand Canyon, we passed numerous remnants of the Triassic ? Red Beds left by erosion since the Pliocene uplift. At no place here did we get a section from the underlying Kaibab limestone, which is frequently exposed, into these red Moenkopi beds. Two miles southeast of Hull Spring, to the southwest of the trail, a partial section in the Moenkopi consists of 80 feet of thinly bedded red sandstones, with many ripple-marks and sun-cracks at its base; above this 10 feet of coarse yellow sandstone containing many selenite veins and bits of wood and charcoal. Throughout the entire region recent cinder cones and lava-flows and ridges of a more or less vesicular malpais (remnants of older lava-flows) are numerous.

A summary of the detailed section made in the Upper Kaibab limestone down the Red Canyon trail, at the Grand Canyon of the Colorado, is as follows:

	Feet
1. Gray limestone full of siliceous concretions.........................	115
2. Alternating light gray and brownish gray limestone..................	152

Many beds are full of siliceous concretions of various sizes. Several of the beds weather back more rapidly than the others, thus producing cave-zones, though no caves were walled up or gave other evidence of having been inhabited by the ancient Cliff-dwellers.

Beneath this are 130 feet of alternating red and gray sandstone belonging to the middle Kaibab. These beds are usually cross-bedded and have a calcareous cement.

Among the small fossils collected from the uppermost beds were noted:

Bakewellia parva M. & H.	r
Astartella gurleyi White	R
Plagioglypta canna White	c
Cf. *Euphemus carbonarius* (Cox)	r
Cf. *Murchisonia ? terebra* White	r

d. NAVAJO SPRING

From the Grand Canyon to just north of the Little Colorado River, at Tanners Crossing, the trail rests upon the Upper Kaibab limestone; north of this, through the Painted Desert to Cedar Ridge, it runs over the Moenkopi and Shinarump, while to the north of Cedar Ridge, and thus to Navajo Spring, it again runs largely over the upper Kaibab limestone. Contact between the Kaibab and Moenkopi was frequently noticed from Cedar Ridge north. Immediately to the south of Navajo Spring occurs the following typical section:

	Feet
1. Red Moenkopi shales.	
2. Greenish shales (included with the Moenkopi)	5
3. Kaibab limestone	8

The upper 2 feet of this limestone contain much limestone breccia, while its uppermost surface is slightly uneven. As the junction of the Kaibab and Moenkopi thus give indications of an erosion interval and the strata have similar dips, the contact of the strata is a disconformable one.

e. HOUSE ROCK VALLEY

From Navajo Spring to Lees Ferry the trail passes over the Kaibab and Moenkopi beds in approximately equal proportions; and again, west of the Colorado River, to the southwest of Lees Ferry, for some 10 miles. Beyond this to House Rock Valley it runs entirely upon the sands of the Moenkopi and Shinarump. These sands and clays mantle the hard Kaibab limestone only for several miles to the south of the trail, as they do to the west of the Echo Cliff trail; beyond this the rapid erosion caused by the deep Colorado River has in most cases removed these softer strata. This rapid erosion causes numerous land slides in both the Vermilion Cliffs and Echo Cliffs.

The upper Kaibab limestone is well exposed along the western edge of House Rock Valley. The following section was made at the southern end of this valley, in a canyon immediately west of House Rock Ranch. This canyon is cut into the east Kaibab Monocline, the great fold, which, carrying these strata upward to the west to an elevation of 2,500-4,000 feet higher than the Marble Platform, forms the Kaibab Plateau. The winding canyon was apparently made by a meandering stream let down upon this ancient monocline by the plateau-like Pliocene upheaval. This section, like the others, was made from the top downward.

	Feet
1. Brownish yellow limestone	14

This bed, owing to the soft underlying shales, stands out as a prominent brownish yellow cliff. Its upper portion is especially full of hard quartz concretions, which, with their coating of desert varnish, stand out from the yellowish limestone as conspicuous black nodules. The extreme upper portion contains more or less limestone breccia. No fossils were found here.

Resting upon this limestone, Professor Johnson found, 5 to 8 miles to the south, the red Moenkopi shales. We note in locality 2 an anticipation of the Moenkopi red mud conditions in Upper Kaibab times.

	Feet
2. Red arenaceous shale with a calcareous cement alternating with yellowish limestone	12

Both the red shale and the limestone are cross-bedded. The only fossil found was a single imperfect specimen of *Productus* cf. *ivesi* Newberry.

	Feet
3. Dense brownish gray limestone	7
No fossils were noted.	
4. Originally a light gray limestone, now much of it silicified	23

The entire thickness is conspicuous for its cross-bedding. Small siliceous concretions are numerous. Some beds have a slightly green color. No fossils were found.

	Feet
5. Very light gray limestone	16

Many concretions, large and small, present but apparently no fossils.

	Feet
6. Alternating light gray and brownish gray limestone	13

Concretions few. Fossils apparently confined to the numerous crinoid joints.

	Feet
7. Light gray limestone	8

Concretions and fossils rather abundant.

Crinoid joints	c
Cf. *Septopora biserialis* (Swallow)	c
Productus ivesi Newberry	r
P. occidentalis Newberry	c
Composita subtilita (Hall)	c

	Feet
8. Brownish gray limestone	7
Fossils and concretions rare.	
9. Brownish gray limestone	24

These strata contain many concretions, both small and large, the latter varying from 5 to 9 inches in diameter. Two caves showing signs of former occupation by the Cliff-dwellers were noted.

The very abundant fossils include—

Lophophyllum profundum E. & H.	c
Crinoid joints	C
Septopora biserialis (Swallow)	c
Meekella pyramidalis Newberry	c
Productus ivesi Newberry	c
P. occidentalis Newberry	c
P. cf. *semireticulatus* (Martin)	r
Pustula nebraskensis (Owen)	r
Spiriferina kentuckiensis (Shumard)	c

Feet

10. Light greenish gray limestone.. 4

This bed is very full of large concretions. It weathers back rapidly, forming caves, some of which noted had been occupied by the ancient Cliff-dwellers.

The fossils collected are

Lophophyllum profundum E. & H.	r
Crinoid joints	C
Productus ivesi Newberry	r

Feet

11. Light brown limestone with few concretions........................ 5

The few fossils include

Crinoid joints	C
Productus ivesi Newberry	r

Feet

12. Light brown limestone full of irregularly scattered siliceous concretions 12

The abundant fossils include

Crinoid joints	C
Productus ivesi Newberry	c
Meekella pyramidalis (Newberry)	c

The following fossils were found in talus from the above section:

Lophophyllum profundum E. & H.	c
Chætetes milleporaceus E. & H.	r
Cf. *Septopora biserialis* Swallow	R
Productus ivesi Newberry	r
P. occidentalis Newberry	C
P. cf. *costatus* (Sowerby ?) de Koninck	R
Pustula punctata (Martin)	r

Cf. *P. nebraskensis* (Owen)	R
Chonetes granulifer Owen	c
Squamularia perplexa (McChesney)	c
Composita subtilita (Hall)	r
Pseudomonotis hawni M. & H.	r
Aviculopecten coloradoensis (Newberry)	r
A. occidentalis (Shumard) ?	r
Euphemus carbonarius (Cox)	r

f. KAIBAB PLATEAU

Westward up the East Kaibab monocline and over the Kaibab Plateau the trail rests upon the extension of the higher strata exposed in the House Rock Valley section. On the plateau, about 8 miles in an air-line west of the preceding section and about 3 miles south of Jacobs Lake, the following fossils were collected. They come largely from a brownish gray limestone which corresponds to locality 9 of the House Rock Valley section. A few fossils may have come from light gray limestones 20 feet above.

Lophophyllum profundum E. & H.	C
Orthotetes crassus (Meek and Hayden)	r
Cf. *O. robustus* (Hall)	r
O. sp.	r
Derbya ? crenulata Girty	r
Meekella pyramidalis Newberry	C
Chonetes granulifer Owen	c
C. cf. *variolatus* (d'Orbigny)	r
Productus occidentalis Newberry	C
P. ivesi Newberry	c
P. costatoides Swallow	C
Pustula punctata (Martin)	r
Dielasma bovidens (Morton)	r
Spiriferina campestris White	r
Aviculopecten coloradoensis (Newberry)	r
A. occidentalis (Shumard)	r
A. sp.	R

g. KANAB PLATEAU (NORTHEASTERN)

The descent to the down-faulted Kanab Plateau was made by Jacobs Canyon. Immediately northwest of the point where this canyon debouches upon the lower plateau the following section in the Moenkopi was noted in a low hill:

1. Yellowish limestone with many siliceous concretions.

Here were obtained the following fossils:

Cf. *Bakewellia parva* M. & W.	r
Pseudomonotis ? sp.	r
Cf. *Chiton carbonarius* Stevens	R
Cf. *Strophostylus nanus* (M. & W.)	c
Strophostylus sp.	R
Turritella ? sp. (small)	c

2. Red arenaceous shales and sandstones.
3. Limestone largely silicified.

h. TOROWEAP VALLEY

Traveling northwestward to southern Utah, and then toward the southwest to Pipe Spring, our next encounter with Moenkopi fossil-bearing strata was some 15 miles southwest of Pipe Spring, at Wild Band Pockets. From here southwestward to the Toroweap Valley fossils were collected from several sections. We will list the sections from the Toroweap Valley northeasterly. This progression from south to north, through the gentle northward dip of the strata makes the northern sections expose correspondingly higher beds than the southernmost. The following section was taken near the middle of the Toroweap Valley. In the very limited time at our disposal while at this section it was impossible to do more than estimate the thicknesses of the various beds.

	Feet
1. Yellowish arenaceous limestone	10±

Apparently from this limestone, exposed farther up the valley, was collected *Leda obesa* (White) R.

A thin limestone slab upon the talus, which appeared to have come from rocks a short distance above this locality, contained numerous specimens of *Bakewellia parva* M. & H. The character of rock and fossils appears to correlate this with the Wild Band Pockets exposure.

	Feet
2. Reddish shale alternating with white and gray thin-bedded gypsum	25±
3. Gray limestone	10±
4. Alternating red shale and white gypsum	60±
5. Massive gray limestone containing many siliceous concretions and many fossils	275±

The following fossils were obtained here:

Productus ivesi Newberry	c
P. occidentalis Newberry	c
Cf. *Pustula nebraskensis* (Owen)	r
Squamularia perplexa (McChesney)	r

	Feet
6. Alternating thin, reddish brown shale and gray gypsum	200±
7. Gray thin-bedded fossiliferous limestone	160±

Among the fossils noted was:

Productus ivesi Newberry	c

Farther down the valley the gray, cross-bedded Coconino sandstone comes in beneath the limestone of locality 7, which in turn rests upon the red shales of the Supai formation. Localities 7, 6, and 5 are respectively the lower, middle, and upper Kaibab, 1 to 4 the lowest Moenkopi.

From the upper Kaibab, at the eastern foot of Mount Trumbull, were collected:

Productus occidentalis Newberry	c
P. ivesi Newberry	c

i. SOUTHWEST OF SAWYERS TANK

The rocks from which the following fossils were collected were exposed just north of a partially eroded cinder cone several miles southwest of Sawyers Tank. The very fossiliferous strata consisted of some 10 feet of yellowish, arenaceous limestone with numerous siliceous concretions underlain by red, gypsiferous shales.

Meekella pyramidalis Newberry	c
Cf. *Dielasma bovidens* (Morton)	c
Composita subtilita (Hall)	r
Nucula perumbonata White	C
Cf. *Aviculopinna peracuta* Shumard	r
Pseudomonotis inequistriata Beede	r
Aviculopecten coloradoensis Newberry	r
Cf. *Entolium aviculatum* Swallow	r
Lima ? sp. *a*	c
Lima ? sp. *b*	c
Lima sp. *c*	c
Plagioglypta canna White	c
Euphemus carbonarius (Cox)	r
Patellostium nodocostatum (Gurley)	C
Cf. *P. ourayense* (Gurley)	r
Warthia americana Girty	R
W. sp.	c
Pleurotomaria grayvillensis N. & P.	c
Murchisonia ? terebra White	r
Cf. *Strophostylus nanus* (M. & W.)	r

j. SAWYERS TANK

Immediately southwest of Sawyers Tank occurs the following section:

	Feet
1. Yellowish, apparently unfossiliferous, limestone	5
2. Red shale	10
3. Yellowish, arenaceous, fossiliferous limestone	10

Here were collected the following fossils:

Pseudomonotis hawni M. & H.	c
P. inequistriata Beede	c
Pseudomonotis ? sp.	r
Aviculopecten occidentalis (Shumard)	c
Aviculopecten ? sp.	r
Plagioglypta canna White	C

	Feet
4. Alternating cross-bedded sandstone, red shale, white gypsum, and yellowish limestone	35+

In the limestones occur frequent external molds, accompanied more rarely by internal molds, of—

Cf. *Plagioglypta canna* White	c

This section appeared in the field to correspond to the upper portion of the Toroweap Valley section.

k. SOUTHWEST OF WILD BAND POCKETS

This section is 3 miles southwest of Wild Band Pockets.

	Feet
1. Gray cross-bedded sandstone	15
2. Gray conglomerate	15
3. Yellowish shaly arenaceous limestone	8
4. Greenish shales alternating with gray arenaceous limestone	15
5. Yellowish arenaceous limestone	15

These beds are filled with small siliceous concretions and with fossils, both very commonly stained red. This is the northward extension of the limestone from which the fossils were collected at the section several miles southwest of Sawyers Tank. The lithology, rock succession, fossils, and even the red staining of concretions and fossils, are similar in each section.

6. Red shale.

The following fossils were collected from locality 5:

Cf. *Orbiculoidia nitida* (Phillips)	R
Cf. *Dielasma bovidens* (Morton)	r
Edmondia subtruncata Meek	r
Nucula perumbonata White	r
Leda obesa (White)	r
Allorisma sp.	r
Cf. *A. gilberti* (White)	r
Lima ? sp. *a*	c
Plagioglypta canna White	C

Euphemus carbonarius (Cox)	c
Patellostium nodocostatum (Gurley)	C
Cf. *P. ourayense* (Gurley)	C
Cf. *Warthia americana* Girty	r
W. sp.	C
Turritella ? sp. (small)	r
Pleurotomaria grayvillensis N. & P.	r
Murchisonia ? terebra White	r

l. WILD BAND POCKETS

Near the Wild Band Pockets the fossiliferous beds exposed in the section 3 miles to the southwest dip beneath the surface of the plateau. On them rests an alternation of red shales and gray shaly limestone. Beds of the latter vary in thickness from five to 10 feet, being thinner than the red shale beds. Where these strata were exposed in a butte the following fossils were collected from the lowest limestone bed found there:

Parallelodon ? sp.	r
Bakewellia parva M. & H.	c
Schizodus meekanus Girty	r
S. sp.	R
Aviculopecten occidentalis (Shumard)	r
Astartella gurleyi White	r
Plagioglypta canna White	C
Turritella ? sp. (small)	c

m. WORKMAN SPRING (UTAH)

	Feet
1. Greenish to gray calcareous shales and arenaceous limestones.........	25

These beds are fossiliferous, in places being very full of crinoid joints.

	Feet
2. Reddish, gypsiferous shales......................................	20+

This section appears to be somewhat higher than the one at Wild Band Pockets, though still in the lower Moenkopi. The Shinarump conglomerate caps the sides of the valley far above.

The following fossils were collected from the greenish shales and limestones:

Pentacrinus sp.	c
Spirorbis sp.	c
Lingula sp.	R
Pugnax osagensis Swallow	c
Cliothyridina orbicularis (McChesney)	c
Bakewellia parva M. & H.	c
Aviculopecten sp.	R

Pleurophorus ? sp.	r
Pleurotomaria sp.	R
Cf. *Strophostylus nanus* (M. & W.)	r
Turritella ? sp. (small)	r

n. HURRICANE (UTAH)

Northwest of Workman Spring the Hurricane Cliffs again expose the upper Kaibab limestone. Near the hamlet of Hurricane, immediately south of the Virgin River, this grayish Kaibab limestone is overlain by the red and green shales of the Moenkopi.

The following fossils were collected from the limestones:

Orthotetes crassus (M. & H.)	r
Chonetes geinitzianus Waagen	c
Cf. *C. granulifer* Owen	R
Productus occidentalis Newberry	c
P. ivesi Newberry	C
Pustula punctata (Martin)	r
Cf. *P. nebraskensis* (Owen)	r
Spiriferina campestris White	c
Squamularia perplexa (McChesney)	c
Composita subtilita (Hall)	c
Aviculopecten coloradoensis (Newberry)	r
Phillipsia sp.	r

Tabular List of Species, with Distribution

In the table showing the distribution of species the Kaibab and Moenkopi sections are each grouped separately. Only in section *h* were both Moenkopi and Kaibab fossils collected from the same section; thus the two fossils found here in the Moenkopi (*Leda obesa* R, and *Bakewellia parva,* c) are not listed in the table below.

The following abbreviations are used:

C = very common, c = common, r = rare, R = very rare. The names of the lettered sections are given in the table of contents.

Species	Kaibab								Moenkopi					
	a	b	c	d	e	f	h	n	g	i	j	k	l	m
Corals														
Lophophyllum profundum E. & H.					c	C								
Chaetetes milleporaceus E. & H.					r									
Crinoids														
Crinoid joints	r	r	r		C	c	c	r						r
Pentacrinus sp.														c
Worms														
Spirorbis sp.														c
Bryozoans														
Septopora biserialis Swallow					c									
Brachiopods														
Lingula sp.														R
Orbiculoidea nitida (Phillips)												cf.		
Orthotetes crassus (M. & H.)						r		r						
O. robustus (Hall)						cf.								
O. sp.						r								
Derbya ? crenulata Girty						r								
Meekella pyramidalis (Newberry)					c	C				c				
Chonetes geinitzianus Waagen								c						
C. granulifer Owen					c	c		F						
C. variolatus (d'Orbigny)						cf.								
Productus ivesi Newberry		c			c	c	c	C						
P. occidentalis Newberry					C	C	c	c						
P. costatoides Swallow						C								
P. costatus (Sowerby ?) de Koninck					cf.									
P. semireticulatus (Martin)					cf.									
Pustula punctata (Martin)					r	r		r						
P. nebraskensis (Owen)	cf.	cf.			r		cf.	cf.						
Pugnax osagensis Swallow														c
Dielasma bovidens (Morton)						r				cf.		cf.		
Squamularia perplexa (McChesney)					c		r	c						
Spiriferina campestris White						r		c						
S. kentuckiensis (Shumard)					c									
Cliothyridina orbicularis (McChesney)														c
Composita subtilita (Hall)	r				c			c		r				
Amphineurans														
Chiton carbonarius Stevens									cf.					

	Kaibab								Moenkopi					
Pelecypods	a	b	c	d	e	f	h	n	g	i	j	k	l	m
Edmondia subtruncata Meek												r		
Nucula perumbonata White										C		r		
Leda obesa (White)												r		
Parallelodon ? sp													r	
Pinna sp		R												
Acivulopinna peracuta Shumard										cf.				
Bakewellia parva M. & H.			r						cf.				c	c
Pseudomonotis hawni M. & H.					r						c			
P. inequistriata Beede										r	c			
P. ? sp									r		r			
Myalina ? sp													r	
Schizodus meekanus Girty													r	
S. sp													R	
Aviculopecten occidentalis (Shumard)					?	r					c		r	
A. coloradoensis (Newberry)					r	r		r		r				
A. sp						R					r			R
Entolium aviculatum Swallow										cf.				
Lima ? sp. *a*										c		c		
Lima ? sp. *b*										c				
Lima sp. *c*										c				
Pleurophorus ? sp														r
Astartella gurleyi White			R										r	
Allorisma terminale Hall	c													
A. gilberti White												cf.		
A. sp												r		
Scaphopods														
Plagioglypta canna White			c							c	C	C	C	
Gastropods														
Pleurotomaria grayvillensis N. & P.										c		r		
P. sp														R
Murchisonia ? *terebra* White		?	cf							r		r		
Euphemus carbonarius (Cox)			cf.		r					r		c		
Patellostium nodocostatum (Gurley)										C		C		
P. ourayense (Gurley)										cf.		cf.		
Warthia americana Girty										R		cf		
W. sp										c		C		
Strophostylus nanus (M. & W.)									cf.	cf.				cf.
S. sp									R					
Turritella ? sp. (small)									c			r	c	r
Trilobites														
Phillipsia sp								r						

Notes on Species

The species from the Kaibab limestone are in the majority of cases apparently identical with similar species from the Upper Pennsylvanian and Permian of the Mississippi Valley and farther west. In the Moenkopi, on the other hand, there is a persistent difference, minute in some

species, greater in others, from corresponding species in the Kaibab below. In the former cases the difference is not usually sufficiently great to receive even verietal distinction, in the latter specimens it frequently reaches a specific differentiation. This change is apparently mostly due to the passage of time, not entirely to a different environment. Just as the upper Kaibab limestone, more or less arenaceous, followed the middle Kaibab gypsiferous red beds, so the fossil-bearing arenaceous limestone lenses in the Moenkopi are separated by gypsum-bearing red beds. In each case the fauna lived in shallow, near-shore seas, which were probably only slightly more open in the case of the Kaibab than in that of the Moenkopi.

With the knowledge that Doctor Girty is working on this fauna, it was decided that the description of new species should be based on the larger and geographically more extended collections in the National Museum.

Notes on a few of the species are here appended.

Pentacrinus sp.—This is a new species. It is very small, a rather large joint measuring 3 millimeters in diameter. The depressions of the sides are shallow, a joint varying from a distinctly star-shaped form to almost a five-sided polygon. The elliptical figures upon the face of a joint are broad, filling up the intermediate space with their radii, though inside each ellipse the smooth space is narrow. Axial opening is minute, round.

Cf. *Orbiculoidea nitida* (Phillips).—Our single specimen agrees closely with Walcott's specimen from the Eureka District, Nevada, as figured by him in the U. S. Geological Survey Monograph 8. It has a diameter of 20 millimeters, a height of 4 millimeters, with coarse concentric striæ.

Orthotetes crassus (M. & H.).—All of the specimens identical with this common species are fragmentary. Some of them appear to approach rather closely Girty's Guadalupian *Derbya ? crenulata,* while one from the Kaibab Plateau may be his *Derbya nasuta.*

Chonetes geinitzianus Waagen.—The specimens identified with this species exhibit, when exfoliated, strong radiating markings due to the structure of the shell; where not exfoliated the surface shows numerous minute spine bases.

Pugnax osagensis Swallow.—Our specimens are similar to those described and figured by Girty from the Guadalupian of Texas.[4] The fold and sinus are of moderate strength, with three rounded plications upon the fold and three upon each side, the last lateral plication being faint. Our specimens may be slightly broader in proportion to height than the Guadalupian ones.

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[4] U. S. Geol. Survey, Prof. Paper 58, 1908, p. 317, pl. 24, fig. 16.

Dielasma bovidens (Morton).—One specimen from the Kaibab Plateau may belong to *D. prolongatum* Girty from the Guadalupian.[5]

Cliothyridina orbicularis (McChesney).—Our specimens agree in general with the ones figured by White, under the name of *Spirigera planosulcata* Phillips, in the Report on the 100th Meridian, volume 4, plate 10, figures 5*a-d*.

Plagioglypta canna White.—The surface ornamentation is well shown upon some specimens. There are approximately six rounded, concentric lines in the space of one millimeter. Faint longitudinal striations were also noted upon one or two specimens. Some of the specimens reach a large size, 13 millimeters in diameter—a diameter equal to that of specimens from the Lake Minnewanka region of Alberta.

Euphemus carbonarius (Cox).—With this species are identified specimens which are similar in size and general appearance to Cox's type as figured in the 13th Indiana Survey Report, plate 33, figures 6-8. They have, however, 15-20 (instead of 20-28) revolving costæ. There is no true umbilicus, a shadow depression only being present in this region of the shell.

E. subpapillosus White was noted by Doctor White from Wild Band Pockets,[6] but has failed to make its appearance in our collections.

Nucula perumbonata White.—Our specimens collected from the same locality as White's types are somewhat thinner (that is, measured through the combined valves) than those figured.[7] Otherwise they are apparently identical.

Leda obesa (White).—Our specimens doubtless belong to White's *Nuculana obesa* originally described from the Wild Band Pockets area. They are similar in shape, size, hinge-line, and surface markings. One internal mold shows that there was a rounded internal ridge extending from the beak in a slight curve posteriorly three-fourths of the distance to the edge of the shell. The position of this rather strong internal ridge appears upon the outside of the shell as a faint depression. This depression also occurs in the specimens figured by Girty from the phosphate beds of Wyoming and Idaho.[8] The presence of this internal buttress makes this species approach the genus Cleidophorus.

Bakewellia parva M. & H.—Some of the specimens from the Moenkopi may perhaps have been better identified as *Pteria richardsoni*, described by Girty from the Guadalupian. Since they are poorly preserved, they are included with the other specimens in this wide-spread species.

[5] Op. cit., p. 331, pl. 16, fig. 5.
[6] Contrib. to Inv. Paleont., nos. 2-8, p. 138, pl. 34, fig. 3*a*.
[7] Op. cit., p. 136, pl. 34, figs. 7*a-b*.
[8] U. S. Geol. Survey, Bull. 436, p. 40, pl. 4, figs. 7, 8.

Lima ? sp. *a.*—Shell inflated, most so in umbonal region, the posterior umbonal slope being the more abrupt, and convex in outline; the anterior margin is slightly concave in outline. Ears small, slightly unequal, the anterior one being separated by a rounded groove; the posterior ear, apparently very faint, merges gradually into the body of the shell. Beaks pointed, incurved. Hinge area very broadly triangular, with apparently a central resiliifer. Teeth and muscle impression unobserved. Surface smooth. Length of a large specimen from beak to front, 22 millimeters; Greatest width anterior to mid-length, 18 millimeters.

Lima ? sp. *b.*—This form differs from *Lima ?* sp. *a* in its smaller size (length of average shell, 15 millimeters; greatest width, 12 millimeters), its radially striate surface (twelve rounded striæ in the space of 4 millimeters; these are separated by equal interspaces; the concentric growth lines thus give to the shell a minutely cancellate appearance), and in having its beaks turned toward the convex margin (instead of toward the concave one, as in species *a*). It was at first thought that species *a* and *b* might be opposite valves of the same form, but we apparently have in our collections both valves of species *b* (though only the right one of species *a*).

Lima sp. *c.*—Shell inflated, though less so than in the preceding species. Beaks pointed, separated by a lozenge-shaped area, over which radiate grooves from each beak. Interior unknown. In external appearance it somewhat resembles *Aviculopecten guadalupensis* Girty,[9] from the Guadalupian Permian of Texas. In each the anterior ear is separated from the body of the shell by a prominent, curved, angular groove. But the alternation of broad and rounded with narrow, angular ribs is lacking in Girty's species, as apparently is also the rather distinct posterior ear. In each the radiating ribs number about 20 to a valve, and in length, from beak to opposite edge of shell, Girty's specimen measures 15 millimeters, while ours average 20 millimeters.

Astartella gurleyi White.—Three minute specimens, about 4 millimeters long and high, are identified with White's species. Except that our specimens are smaller (White's type measuring 7 millimeters in length and height) and with a weaker umbonal ridge than is figured,[10] they agree well in the subsquare shell outline, low umbos, and in the surface sculpture, broad concentric furrows separated by sharp linear ridges.

Patellostium nodocostatum (Gurley).—Our numerous specimens approach this species rather closely; an average mature shell measures (in

[9] U. S. Geol. Survey, Prof. Paper 58, 1908, p. 436, pl. 16, fig. 20.
[10] C. A. White: Contrib. to Inv. Paleont., nos. 2-8, 1880, pl. 42, figs. 6*a*-*b*.

millimeters) in height of shell and width of aperture 15 by 15—; the largest specimen in our collection is 20 by 20+. Umbilicus distinct, though small. The peritreme expands rapidly and is broadly rounded across the dorsum. Slit band is sharply defined, but not much elevated. Inner lip with a thick deposit of callus.

In sculpture our specimens, like those noted by Girty from the Manzano group of New Mexico,[11] have six revolving striæ in the space of 5 millimeters, but they have one to six less regularly arranged transverse striæ in 5 millimeters. The transverse striæ are bent backward as they approach the slit band. Near the aperture, the first half inch in mature specimens, the transverse striæ are more regularly arranged and more numerous, 5 to 6 in 5 millimeters. Upon the remainder of the coil, back to the callus, these become broad, rounded, irregular undulations, 1 to 2 in 5 millimeters, though at times a single undulation will be made up of two or three transverse striæ. In addition to these striæ and undulations, growth lines are prominent. In young shells, under 10 millimeters in diameter, these growth lines are the only transverse ornamentation; beyond this size the coarse, transverse undulations make their appearance. The regular, conspicuous revolving striæ occur on the youngest shell noticed. As in the type of this species, the revolving striæ become strongest upon the crests of the transverse striæ, forming there slight nodes.

Possibly some of our small specimens may belong to *Bucanopsis modesta* Girty,[12] but since there are in our collections all stages, from shells with no transverse striæ, or undulations, to those exhibiting these in typical development, it is thought best to consider all as the young of *P. nodocostatum*.

Our form differs from *P. montfortianum* N. & P. in that upon the latter the revolving striæ are of two sizes, the large ones alternating with several smaller ones. In *P. ourayense* Gurley a cross-section of the peritreme is deltoid, pointed at the slit band. In *P. bellum* Keyes the transverse markings go nearly straight across the shell and are not curved backward at the slit band. As there is no published figure of *P. nodocostatum*, definite identification is difficult and our form may prove to be a distinct species.

Cf. *Patellostium ourayense* (Gurley).—A cross-section of the peritreme of Gurley's type specimen[13] shows the sides compressed and narrowly rounded at the slit band—that is, the section is sub-deltoid. A few of

[11] U. S. Geol. Survey, Bull. 389, 1909, p. 102.

[12] Op. cit., p. 103, pl. 11, fig. 1.

[13] Girty: U. S. Geol. Survey, Prof. Paper 16, 1903, p. 471, pl. 10, fig. 10.

our specimens may belong to this species, though the cross-section is more broadly deltoid than in the type.

Warthia americana Girty.—A single specimen from the Sawyers Tank section is identified with this Guadalupian species. The dorsum is helmet-shaped when young, more rounded later at aperture; umbilicus closed; no trace of slit-band or surface ornamentation. It is slightly larger than the specimen illustrated in the Professional Paper 58, plate 23, figure 15.

Warthia sp.—Our collections contain a considerable number of rather poorly preserved shells presenting the following characters: length and breadth subequal (about 17 millimeters), umbilicus closed, dorsum broadly rounded, surface smooth.

Discussion of Age of Formations

IN GENERAL

In the discussion of the age of the Kaibab and the Moenkopi formations it seems well to begin with the Redwall and end with the Chinle. In this way their relation to the formation above and below will appear.

REDWALL LIMESTONE

The Redwall limestone contains typical lower Mississippian fossils. It is correlated with the Escabrosa of southern Arizona, the Madison of Wyoming and Montana, and with the lower Banff shale and lower portion of the upper Banff limestone of Alberta.

SUPAI (LOWER AND MIDDLE)

What appears to be in places the upper portion of the Redwall contains a Pennsylvanian fauna.[14] These massive limestone beds in the western areas of the Grand Canyon region correspond, however, according to L. F. Noble,[15] to the lower Supai red shales and sandstones of the more easterly areas, a transition occurring between these areas. The shales and sandstones of the eastern Kaibab Plateau division of the Grand Canyon area become toward the west more calcareous, with intercalated limestone beds. These in turn give place, in the Kanab Plateau and farther west, to a massive limestone like the Redwall. The region of the Kaibab Plateau was thus apparently, during lower Supai time, the boundary between the open sea to the west and the land to the east.

The fauna of this lower Supai (= uppermost Redwall of western areas)

[14] W. T. Lee: U. S. Geol. Survey, Bull. 352, 1908, p. 15.

[15] Charles Schuchert: Am. Jour. Sci., 4th ser., vol. 45, 1918, p. 358.

is very similar to the Pennsylvanian fauna of Kansas. These two faunas are compared in parallel columns by A. B. Reagen,[16] with the conclusion that out of 36 genera from this "Upper Redwall" 32 occur in the Kansas Pennsylvanian, and of the 32 species from the former 26 are also found in the latter.

Between the Supai, delimited as above, and the Redwall occurs a disconformity, representing the time of the upper Mississippian and portions of the middle Mississippian and lower Pennsylvanian. This makes the Pennsylvanian begin in this region with the deposition of the lower Supai beds after the land period represented by this erosional interval.

SUPAI (UPPER)

According to David White, in a letter to Schuchert,[17] the few fossil plants found in the upper Supai indicate a lower Permian age, or at least an age not lower than the highest Pennsylvanian. These red beds of the upper quarter of the Supai formation are separated from those of the lower three-quarters by a disconformity.

COCONINO SANDSTONE

With the exception of rare amphibian footprints,[18] no fossils have been reported from the Coconino sandstone—a gray to white, strongly cross-bedded formation. It is disconformably separated from the Supai beneath.

KAIBAB LIMESTONE

The Kaibab limestone formation consists of rather thin-bedded, more or less siliceous limestones, including as a medial member one or two hundred feet of gypsiferous red shales and sandstones.

One of the most noticeable peculiarities of the Kaibab fauna is the absence of true Spirifers. Such characteristic, abundant and wide-spread species of the typical American Pennsylvanian as *Spirifer rockymontanus* and *S. cameratus* are wanting here. At the same time pelecypods, especially of the genera Pseudomonotis and Bakewellia, increase in relative abundance. These differences similarly distinguish the Permian from the Pennsylvanian in Kansas.[19] Concerning the correlation of the Kaibab limestone, Girty[20] later concludes that its fauna "contains a number of species which are very similar to, or identical with, species that occur in the Guadalupian fauna, . . . and it seems less improbable

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[16] Centralbl. f. Mineral., 1907, pp. 609-611.
[17] Op. cit., p. 354.
[18] Schuchert: Op. cit., p. 350.
[19] G. H. Girty: U. S. Geol. Survey, Bull. 211, 1903, pp. 73-83.
[20] L. F. Noble: U. S. Geol. Survey, Bull. 549, 1914, p. 71.

than it did several years ago . . . that the Kaibab limestone is of the same geologic age" (that is, undoubted Permian). Schuchert[21] maintains the Permian age of this formation still more strongly, saying "that the Kaibab limestone is of early Permian age is now admitted by most American stratigraphers. This view, however, has been attained rather from its field relations than through a study of its marine fossils."

Throughout Europe the Permian is characterized by a fauna very similar in its general composition to that of the Kaibab. It contains, in abundance, representatives of the brachiopods *Productus, Athyris, Chonetes, Spiriferina,* and the *Orthidæ;* of the pelecypods, *Allorisma, Schizodus, Pseudomonotis, Bakewellia,* and *Aviculopecten,* and the last representatives of the trilobites in the genus *Phillipsia.* Though *Spirifer* is very abundant in the European Permian, its absence from the Kaibab would argue, if anything, a later rather than an earlier age for this formation.

The red shales and sandstones of the Supai formation, with their characteristic cross-bedding, mud-cracks, and raindrop impressions, indicate a terrestrial deposit under arid conditions. Such aridity is similarly indicated in the heavily cross-bedded Coconino sandstone, with evidence that much of it is of wind origin. In the midst of the shallow sea conditions of the Kaibab limestone (indicated by the fauna and by the presence of varying amounts of quartz grains up to a pure sandstone)[22] occur the red, gypsiferous shales of the middle Kaibab, also indicating arid terrestrial conditions. Evidences of aridity increase with the Moenkopi and higher beds. Such prolonged aridity is an additional evidence that these beds were deposited during the almost world-wide aridity of Permian and Triassic times.

The Permian age of the Kaibab limestone is thus indicated by the evidence of wide-spread and prolonged aridity, by the absence of many typical Pennsylvanian species, by the presence of forms characteristic of the Permian of Europe, of that of the Mississippi Valley, and to a less degree of the Guadalupian Permian of Texas (see also "Notes on species"). It is further indicated by the paleobotanical evidence of the Permian, or uppermost Pennsylvanian, age of the underlying upper Supai formation.

MOENKOPI FORMATION

The Moenkopi of the type locality at Moenkopi Wash, north of Tanners Crossing, was, in the field, apparently traced westward to the Virgin River, in Utah. The rapid changes in lithologic character and in thick-

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[21] Op. cit., p. 348.

[22] H. W. and F. H. Shimer: Am. Anthropol., vol. 12, 1910, p. 248.

ness in terrestrial deposits naturally make such work less certain than it would be in the case of a marine limestone. The Moenkopi throughout the area as thus extended, consists of thin-bedded red shales and sandstones, separated at usually rare intervals by limestone lenses. These limestone beds become more frequent from the type locality westward. These limestone beds are usually thin, 5 to 10 feet in thickness; some of them are fossiliferous, containing a marine fauna.

After the deposition of the great thickness of Permian strata—the upper Supai, Coconino, and Kaibab—came a period of erosion. The Moenkopi seems everywhere throughout this portion of Arizona to be separated from the underlying Kaibab by a disconformity.[23] Resting upon the Moenkopi are the Shinarump, and upon this the Chinle, both of Upper Triassic age. Upon purely stratigraphic grounds, therefore, this would tend to place the Moenkopi within the Lower Triassic. The marine invertebrate fossils, however, which at restricted horizons are abundant in the Moenkopi red beds, considerably complicate this stratigraphic simplicity. The majority of the fossils have Permian affinities. With these are associated, however, a number of Triassic forms and others whose nearest relatives have always been considered as belonging typically to the Mesozoic. Abetting this last consideration is the absence from these strata of some of the most typical Permian groups. To take these differences up briefly:

The Moenkopi is characterized by a conspicuous reduction in the brachiopod fauna (see tabular list of species with distribution). Instead of the usually strongly dominant position held by this class in the upper Paleozoic, it here occupies a very insignificant position indeed. The pelecypods are now the most important faunal element, both in number of species and of individuals, with gastropods a close second. In this respect the Moenkopi resembles the English-German lagoon type of Triassic, with brachiopods rare and pelecypods exceedingly abundant.

The Moenkopi fauna is further characterized by an absence of some of the typical Permian genera. There are here, for example, no representatives of *Productus, Spirifer,* or *Chonetes,* which, through the great prolificness of their many species, everywhere assert themselves as the most important elements in the seas during the closing years of the Paleozoic. There are likewise absent from the Moenkopi such other characteristic uppermost Paleozoic genera as *Fusulina, Lophophyllum, Axophyllum,* the *Orthidæ, Stropholosia,* and *Phillipsia.* In the absence of these genera, which, through their many species and innumerable individuals, give to

[23] See also Gregory: U. S. Geol. Survey, Prof. Paper 93, 1917, p. 30.

Permian faunas the world over their characteristic expression, there is lacking in the Moenkopi fauna the common Permian aspect.

In place of the above genera we find in the Moenkopi such typical Mesozoic forms as the crinoid *Pentacrinus,* Triassic ammonites, and the genera *Nucula, Lima,* and small *Turritellas.* When present in abundance, as here, *Nucula* and *Lima* are much more characteristic of the Mesozoic than of the Paleozoic; while the small *Turritellas,* in contradistinction to the large species, similarly characterize the Triassic. Triassic ammonites, though not present in our collections, have been gathered in various sections from Arizona to Idaho in strata of similar age. For example, in western Utah, in Beaver Canyon, 4 miles east of Minersville,[24] these ammonites are accompanied by a fauna similar to that of the lower Moenkopi in our Arizona sections. The strata containing this fauna are limestones similarly intercalated between red shales, which in turn rest upon a more massive limestone faunally similar to the Kaibab of Arizona. These Utah red beds Girty[25] correlates with Walcott's Permian of Kanab Creek in northern Arizona, the Permo-Carboniferous of the Wasatch mountains in northern Utah, and the Lower Triassic (called Meekoceras beds from the Triassic ammonites of this genus present) of southeastern Idaho.[26]

In brief, in the absence of the most typical Permian genera, in the characteristic Triassic reduction of brachiopods and increase of pelecypods, and in the presence of typical Triassic forms, a Triassic age for the Moenkopi appears to be indicated. The persistence of many Permian species tends to place it in the Lower Triassic. If this be true, we had in western North America a region where Permian species persisted until after the ushering in of Mesozoic times. The most typical Permian species had died off with their confrères in other parts of the world, but a few retained sufficient energy to give forth replicas of themselves (though with slight modifications) into Triassic time. The normal open sea of the Lower Triassic, present in California, Oregon, and Idaho, was separated from the lands in the Rocky Mountain region by a lagoon, or lagoons, occupying at times the present areas of northwestern Arizona and western Utah. Into these lagoons came at intervals representatives of the normal sea fauna to the west. The presence of these visitors in these faunally retarded areas is one of the indications of the existence of Mesozoic time in the world at large.

Dr. Girty has for some time tentatively held the Triassic age[27] of this

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[24] U. S. Geol. Survey, Bull. 316, 1907, p. 363.
[25] Op. cit., p. 364.
[26] U. S. Geol. Survey, Bull. 436, 1910, p. 7; also idem., Prof. Paper 93, 1917, p. 31.
[27] U. S. Geol. Survey, Bull. 436, 1910, p. 7.

formation. More lately this belief has become a conviction. In a letter in 1915 to Gregory[28] he says:

"There no longer seems substantial reason to doubt that Walcott's Permian is the Lower Triassic (*Meekoceras* zone) of Idaho and the 'Permocarboniferous' of Utah."

An alternative to the Lower Triassic age of the Moenkopi is that these red sediments were deposited during the Upper Permian, and at this time there had already evolved some forms which later became typical of the Triassic. In this paper, however, we incline to the belief that a period begins with the first distinct appearance of any portion of the fauna typical of it. Just as old leaves may persist upon a tree long after the bursting buds herald the presence of a new period of growth, so a fauna may persist in some favored regions long after the ushering in elsewhere of a new fauna declares that a new period is here.

Shinarump conglomerate.[29]—A gray cross-bedded conglomerate and sandstone. This conglomerate is separated from the Moenkopi below by a strongly expressed disconformity. Gullies in the Moenkopi filled with Shinarump pebbles and fragments of wood are common and wide-spread. Some of its pebbles inclose Permian Fusulinidæ. "The fossil wood and fragments of bones in the conglomerate are believed to have Upper Triassic affinities." [30]

CHINLE FORMATION [31]

The Chinle formation of Gregory (= Ward's upper part of Lithodendron member, his Leroux, and the lowest 100 feet of his Painted Desert formation) consists of variegated, red and purple, thin-bedded gypsiferous marls, shales, sandstones, and concretionary limestones.

There is apparently a slight disconformity at the base of this formation.[32] Vertebrate fossils described some years ago by F. A. Lucas[33] are called by him Upper Triassic in age. These are here "the same combination of belodont and labyrinthodont as in the Keuper" of Europe. The ostracod crustaceans[34] point to the same conclusion.

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[28] Op. cit., p. 31.
[29] Gregory: Op. cit., p. 37.
[30] Gregory: U. S. Geol. Survey, Prof. Paper 93, 1917, p. 41.
[31] Gregory: Op. cit., p. 42.
[32] Gregory: Op. cit., p. 39.
[33] Science (n. s.), vol. 14, 1901, p. 376; U. S. Nat. Mus. Proc., vol. 27, 1904, pp. 193-195. See also: Gregory, op. cit., p. 46.
[34] W. Cross: Jour. Geology, vol. 16, 1908, pp. 107, 108.

Summary

In a two months' trip from the Mogollons (south of Flagstaff), in Arizona, to Hurricane, Utah, fossil collections were made from sections in the Kaibab limestone and Moenkopi shales. The paper discusses eight such sections in the Kaibab formation and six in the Moenkopi. The conclusion is reached that the Kaibab, with its 20 brachiopods, 7 pelecypods, and 2 gastropods, is of Permian age, while the Moenkopi, with its 6 brachiopods, 21 pelecypods, and 11 gastropods, belongs, probably, to the Triassic period. A total of 69 species are listed, 34 from the Kaibab and 43 from the Moenkopi, a few species being present in both formations. Thus in this region, and extending northward into southeastern Idaho, we have (as summarized on pages 485-486) a persistence of some Paleozoic species, continuing with very little change, apparently, into Mesozoic time.

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EVOLUTION OF GEOLOGIC CLIMATES [1]

BY F. H. KNOWLTON

(*Read before the Paleontological Society December 28, 1918*)

CONTENTS

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Introduction

In present-day acceptance the term climate has come to be applied to the atmospheric conditions or weather normal to a given locality or region, especially as affecting life, health, comfort, and the multifarious activities of terrestrial existence. Although there are very considerable areas of the earth's surface that exhibit similar climatic conditions, it needs little reflection to demonstrate that the climate of the earth is by no means uniform throughout. If, for instance, we travel either north or south from the equator, we pass successively through a so-called torrid zone, a temperate zone, and, in polar lands, a frigid zone, each with minor but distinctive modifications. In other words, the present distribution of climate is zonal.

This zonal distribution of climate on the earth, as we know it at the present time, is a phenomenon that appears to have had its origin, or at least its most marked accentuation, during and subsequent to the Pleistocene or so-called Ice Age. Its persistence at the present time is due to the very good reason that we are living in what is either an interglacial cycle, of which there already have been several, or possibly in a period that may represent the permanent waning of the Ice Age. Although as

familiar and as seemingly permanent as this climatic zoning is at the present time, it is believed that it can be conclusively demonstrated that it is more or less abnormal or exceptional—that is, when earth history is viewed as a whole it is increasingly evident that the time during which climate has been distributed in zones represents but a small fraction of geologic time.

The following may be taken as the thesis of the first part of this paper.

> Relative uniformity, mildness, and comparative equability of climate, accompanied by high humidity, have prevailed over the greater part of the earth, extending to, or into, polar circles, during the greater part of geologic time—since, at least, the Middle Paleozoic. This is the regular, the ordinary, the normal condition.[2]

The study of climatic conditions that obtained during the past—the study of fossil climates, so to speak—is beset with some difficulties. Naturally, these conditions can only be interpreted through the impress retained by the physical and biological surroundings, and these are not always of equal distinctness or equal value. It is not the intention in the present paper to consider fully the purely geologic criteria; nor is it the intention, or indeed the desire, to draw any invidious comparisons between the two great classes of biologic criteria, but it is, I believe, generally admitted that plants inherently possess the qualities which permit them to exhibit the more reliable criteria as to the climatic conditions under which they passed through their life processes. A great majority of animals are endowed at some stage in their life cycle with the power of locomotion, which enables them to move about more or less freely in response to various external forces, perhaps the most important of which is that of the climatic environment. When, for whatever reason, the conditions become unfavorable, the animal is more or less free to change its habitat; but with the plant it is usually quite different.

Part I. Paleobotanical Evidence in the Interpretation of geologic Climates

TEMPERATURE TOLERATION IN PLANTS AND ANIMALS

Before presenting the paleobotanical evidence regarding ancient climates, it is pertinent to call attention to the fact that, whatever the decision may be regarding geologic climates, it is certain that since at least Algonkian time terrestrial temperatures have been stabilized be-

[2] David White and F. H. Knowlton: Science, new ser., vol. 31, 1910, p. 760.

tween relatively narrow limits, else life could not have been continuous, as we have every reason to believe it has been. "The control of secular climates," says Professor Chamberlin,[3] "is obviously a condition prerequisite to biologic continuity. The preservation of a narrow range of temperature and a limited variation of atmospheric constituents throughout the millions of years of the biologic past was absolutely essential to organic evolution. Continued preservation for millions of years to come seems equally a condition precedent to an intellectual and spiritual evolution commensurate with the physical and biological evolutions that have preceded it."

The vital processes in plants are practically suspended when the temperature falls below 32° F. (O. C.), though during their resting stage many plants, especially in polar lands, are accustomed to endure a temperature of —70° F. or even lower. The opposite extreme is shown by certain simple types of algæ that thrive in the waters of hot springs under a temperature approximating 200° F., and there is very considerable diversity of algal life in thermal springs with temperatures ranging between 140° F. and 180° F.

It is now known that certain bacteria and protozoa when in an encysted or resting stage can successfully endure a temperature of nearly —200° C. for six months and about —250° C. for shorter periods, and the spores of certain other bacteria can withstand for a shorter time a temperature as high as 120° C. These extremes of tolerance, however, are far greater than the organism could endure when in active growth.

The optimum temperature for plant life is usually between 22° and 37° C. (71° and 98° F.). There is, however, quite a wide range for species and even different individuals of the same species. "In tropical plants the minimum temperature may be as high as +10° C., while those of higher latitudes, where the first plants of spring often grow through a covering of snow, as well as those of the higher Alps and polar regions, grow vigorously at a temperature but little above zero."—Strasburger.

The extremes of temperature between which animal life is possible are apparently less than for plants. For instance, no known animal finds a congenial habitat, either aquatic or terrestrial, that has a permanent temperature of 200° F., though many of them can and do carry on their essential life processes at a temperature considerably below 32° F., yet were such temperature to be reached they must ultimately succumb, since in its last analysis "all food of all animals is supplied by plants."

From the foregoing discussion it appears that the range of biologic

[3] T. C. Chamberlin: Jour. Geology, vol. 14, 1906, p. 363.

toleration must be less than 200° F.—that is to say, a permanent raising of terrestrial temperatures above 200° F., or a lowering below 32° F., would have inhibited life on this globe. It is of course possible that life forms were more tolerant of temperature range in the earlier geologic ages, but from what is now known of the nature and demands of protoplasm this seems very unlikely.

PALEOBOTANICAL CRITERIA FOR DETERMINATION OF CLIMATIC CONDITIONS

During the slightly more than one hundred years that practically cover the period of the scientific study of paleobotany, a vast body of facts has naturally been accumulated regarding the vegetation of the past. The imperfection of the paleontologic record of course still leaves many lamentable gaps in our knowledge, though many of these are gradually being filled in. At the same time the study of the living floras, by which and through which the ancient floras must in large measure be interpreted, has also progressed by leaps and bounds. Through keenly prosecuted systematic studies the floras of the world have been made known to us, while through the newly developed study of ecology we have come to know much of the physical and environmental requirements of these floras. To this must also be added a greatly increased knowledge of histological and structural details, as well as marked advance in embryological, developmental, and evolutionary knowledge. Each of these factors is, to a great or less extent, now available in interpreting the floras of the past.

In seeking to ascertain the bearing of the floras on the climatic conditions that obtained at the time they were living, it is desirable to set forth the criteria that must form the basis of such judgment, and which it is believed will furnish the most reliable evidence. As I have stated on a former occasion:

"In drawing conclusions from individual organisms in an inquiry of this kind, dependence must of course be placed on our knowledge of the present-day requirements of similar species, and the results must always be subject to possibility of error from two sources—first, from the incorrect placing biologically of the organism, and, second, from the fact that its requirements in past geologic time may not have been the same as those which now dominate the life activities of its supposed analogue. However, when all the elements of a flora appear to point in the same direction the liability to serious error is minimized, if not eliminated."

In the present connection the criteria that may seemingly be relied on to furnish a reliable interpretation of climatic conditions have been so succinctly enunciated by White in his paper on the Origin of coal that I

venture to quote it entire. Although it was drawn up especially to cover the conditions during the deposition of the great coal deposits, and more particularly the Paleozoic coals, it nevertheless applies with equal force to all horizons. White[4] writes as follows:

"During the times of deposition of most of the principal coal groups the climate has been characterized by (1) general mildness of temperature, approaching in most cases tropical or subtropical; (2) conspicuous equability or approximation to uniformity of climatic conditions, which, with a few exceptions, appear to have lacked cold winters or severe frosts; (3) a generally high humidity, the rainfall being from moderately heavy to very heavy and fairly well distributed through the year, though in many cases there is evidence of the occurrence of dry periods, which, however, seem ordinarily to have been comparatively short and not severe; (4) an amazingly wide geographical distribution of these genial and equable climates, which occurred seemingly in almost uniform development simultaneously in the high and in the low latitudes of both the Northern and the Southern Hemispheres. This shows either that the essentially uniform climatic conditions were truly extraordinary in geographic extent, with little regard to modern climatic zones, or that the formation of coal was mainly confined to the areas of the above-prescribed climatic environment.

"The principal criteria as to climate offered by the fossil plant remains preserved either in the coal or in the enveloping shales and sandstones and, serving as a basis for the conclusions stated above, may be summarized as follows:

"1. Relative abundance or luxuriance and large size of terrestrial vegetation—that is, rankness of growth—indicating favorable conditions of temperature, humidity, etc.

"2. Character, condition, and amount of the land-plant material preserved as coal or carbonized in the rocks. The formation of xyloid coal of the ordinary types, composed mainly of subaerial vascular plant remains, indicates humidity. In regions of cool temperature the humidity required for the formation of peat—the initial state of coal—is moderate; in warmer climates, where decay is more rapid, not only must the humidity be greatly increased in order to provide the necessary wetness to retard decomposition, but there must be no long dry season of the year for the too great reduction of the water cover. The observations of peat formation at the present day in tropical climates show that in order to permit the deposition of peat the rainfall must be both very heavy and fairly well distributed through the entire year.

"3. Great radial distribution, seemingly over the greater part of the earth, and especially over wide ranges of latitude, of identical species and genera in characteristic association, indicating the extension of approximately uniform climatic conditions in these regions. Floras identical, or essentially identical, in remote or detached regions can owe their identity to no other cause than approximate continuity of the environment, whether that continuity is geographic or chronographic. Conversely, migration of a flora without change is possible only through regions of essentially identical environmental conditions. Illustrations are found in the Carboniferous, Triassic, Jurassic, and Lower

[4] David White: The origin of coal. U. S. Bureau of Mines, Bull. 38, 1913, p. 67.

Cretaceous floras, and even to a remarkable degree in the Upper Cretaceous and Tertiary floras.

"4. Presence of types known to be adapted to or confined to the warm temperatures or moist climatic conditions of the present day, types that though now extinct once lived in association with other types of ascertained tropical or humid habitats, and types whose descendants or nearest surviving relatives are characteristic of warm climates. Examples are cycadalean types in Carboniferous, Triassic, Jurassic, Cretaceous, and, finally, in the Oligocene, in association, since the Trias, with living tropical and subtropical genera or families; the presence of tree ferns in nearly all periods of coal formation; palms, cinnamon trees, climbing ferns, and many other tropical or subrtopical types in the Upper Cretaceous; and bread-fruit trees, etc., in the Lower Tertiary.

"5. Structures of the plants themselves. Features showing rapidity of growth—that is, abundant rainfall, mild or warm temperatures, etc.—conditions favorable to rapid growth:

"(*a*) Very large size of the cells, many with thin walls, and large intercellular spaces, indicating rapid growth and abundant moisture, noticeable in the woods found in and with most coal.

"(*b*) Large size of fronds and leaves, indicating conditions favorable to growth and, at present, characteristic of moist tropical habitats.

"(*c*) Frequency of laciniate or much-dissected, drooping fronds and pendent branches or twigs seemingly adapted to facilitate the run-off of rain, and protection of the stomata in grooves on the under sides of many leaves, as in the Lepidophytes of the Carboniferous.

"(*d*) Smoothness of bark, which is often thick, pointing toward warm humid swamps.

"(*e*) Absence of growth rings in the woods of the older coal formations, showing climatic conditions favorable to practically uninterrupted growth, and the absence of long dry seasons or winter frost. Such absence of rings, when noted in all the associated types, plainly shows the approximation to equability of climate.

"(*f*) Wide occurrence in the Paleozoic coal fields of heterospory, requiring prevalent swamp conditions; and the occurrence of delayed fertilization and of devices for seed flotation.

"(*g*) The development of subaerial roots in many of the types.

"6. A circumstance that may be observed in most coal fields in proof of abundant rainfall at the time of coal formation is the continuity of many coal benches or strata from one hollow or pan over the intervening shoal or sand bar into the next pan or along the slight gradients of the base levels, a circumstance impossible except with sufficient rainfall to saturate the vegetal cover and maintain a ground-water table of retarded drainage held by the obstructing vegetation.

"7. Two other interesting lines of evidence for the warm climate of the Carboniferous are seen, as pointed out by Potonié, in (*a*) the development of more flowers and fruits on the lower parts of stems and branches, as in Ulodendron, Sigillaria, and many Calamariæ, a characteristic of dense tropical forests at the present time, and (*b*) the presence in many ferns of Aphlebiæ, which today are unknown except in tropical types."

EVIDENCE OF THE FLORAS

Algonkian flora.—So far as now known, the first plants of which we have a definite record occur in the Algonkian formations of the Cordilleran area of western America. From these beds, which are more than 5,000 feet thick and fully 6,000 feet below the overlying Cambrian, Mr. Walcott[5] has described 6 genera and 10 species of organisms that had the power of secreting and depositing calcium and magnesium carbonate. They appear to be algæ closely allied to the Cyanophyceæ, or blue-green algæ, and are believed to have been largely instrumental in depositing the great pre-Cambrian limestones of western America. The waters in which these algæ lived are thought to have been fresh.

These organisms are so obscure and still so little understood that it is hazardous to venture an opinion as to the temperature conditions under which they might have lived. Walcott makes the following observations as to the climate of the time:

> "The presence of great thicknesses of red sandstones and shales in the Algonkian sections of the Grand Canyon and Belt series of Montana suggests an arid, possibly a cold, climate. Opposed to this are the great limestone beds which indicate a fair supply of water to form inland seas whose temperature was sufficiently high to permit of an adequate growth of algæ of a simple type that served as the agency for the precipitation of vast quantities of calcareous matter."

At this point I may stop for a moment to consider the deductions to be drawn from the presence of red beds. Most geologists interpret the presence of red beds as an indication of aridity. On the contrary, it seems to me that the evidence is fairly conclusive that red beds may have been formed under conditions of warm, moist climates. Briefly, the reasons for this view are as follows: 1. So far as known, red beds are not being formed at the present time in any desert region, but as maturely weathered residual soils they are being formed in southern temperate and tropical regions, and in warm, moist climates. 2. The plants found in red beds, as, for example, in the Permian, Triassic, etcetera, are not pinched or depauperate, nor do they exhibit marked xerophytic adaptations. Moreover, very considerable deposits of coal are found in red beds in many parts of the world, which implies the presence of swamps but little above sealevel.

On the basis of the assumption that the extensive red beds in the Algonkian indicate warm, moist climatic conditions, and that the algæ call for warm waters, I venture to interpret the climate of at least

[5] C. D. Walcott: Pre-Cambrian Algonkian algal flora. Smithsonian Misc. Coll., vol. 64, no. 2, 1914, pp. 77-156, pls. 4-23.

upper Algonkian time as warm, perhaps subtropical. Coordinative data from the side of animal life consist of about five types of trails or burrows and fragments of a supposed crustacean (*Beltina*).

Cambrian and Ordovician floras.—Plant life of Cambrian and Ordovician time is practically unknown. Walcott speaks of having seen a number of algal forms in certain Cambrian formations that appear to be at least generically similar to those described by him from the Algonkian, but they are still undescribed. He adds: "The field of investigation, however, is a large one, and promises most interesting results."

An appeal to the animal life of the time shows that it was becoming increasingly abundant and diversified, and, so far as I am able to learn, it indicates warm waters, wide—practically world-wide—distribution, and absence of marked climatic differentiation. As an example, mention may be made of certain stony corals (Archæocyathidæ) of the Cambrian that are found in California, Labrador, New Liberia (70° N.), Sardinia, Spain, Australia, and Antarctica.

There is every reason to suppose that plants were equally abundant and equally undergoing diversification; but, as they were still confined to an aqueous habitat, they have left little trace of their existence, unless they had the power of secreting lime.

Silurian floras.—Our knowledge of the plant life of the Silurian is still extremely limited. It consists in the main of marine algæ, and of these some 15 or 20 supposed generic types are recognized. A few of the best defined types are thought to indicate with a reasonable degree of certainty the presence of the modern groups Caulerpaceæ, Floridaceæ, and Fucaceæ, but the majority are so poorly defined that it is unwise, if not impossible, to attempt to refer them with certainty to living groups.

Devonian floras.—The coming of Devonian time witnessed one of the most important events that has been recorded in the entire history of plant life. It was then for the first time—at least in force—that plants emerged from an aqueous habitat and began their conquest of the land. In early Devonian time the land-masses were in the main low and flat, with low coasts and deep bays bordered by broad marshes, in which the surface was intermittently covered by brackish or fresh waters that seem likely to have offered a favorable setting for this momentous transformation. White [6] says:

"It seems permissible to suppose that the ancestors of the land plants were amphibious, perhaps growing where exposed only at the recession of the tide. It is, I believe, probable that these early plants were but sparsely foliate,

[6] David White: Upper Paleozoic floras, their succession and range. Outlines of geologic history, 1910, p. 140.

their leaves being either spinoid or very small, and delicately thin. The latter were probably dorsally rolled at first during the intervals of exposure to the air. . . . The expansion of a proper leaf and the production of an aerial system of transpiration were presumably gradually evolved as the plant became weaned from its subaqueous habitat, and accustomed to gain its food from the atmosphere. However this may be, it is fairly clear that the early representatives of the dominant Devonian types were of limited foliar expanse. . . . It also appears that to support their weight in air a reinforced cuticle, later developed as a very thick and complicated cortex, was made to serve until a woody axis, and, eventually, secondary wood should be fully produced by their descendants. From the characters of some of the fossils it seems probable that, unable to stand alone, they sprawled or clambered about on the ground or on other plants."

The known land flora of the early Devonian is very scanty indeed. The vegetation of the time had but recently emerged from an aqueous habitat, and, it is to be presumed, was of thin-leaved, hence weak, flaccid type, differing but little from the water-inhabiting ancestors. The matrix in which it should be found is coarse-grained, and, moreover, the vicissitudes to which the rocks were subsequently subjected have made it almost impossible to recover recognizable plant remains, even if such were present.

But evolutionary development was rapid and by Middle Devonian time a considerable number had assumed an upright position, though of very strange and forbidding aspect. Perhaps the most characteristic types are *Psilophyton, Arthrostigma, Rachiopteris,* and the peculiar fern-like plant known as *Archæopteris.* According to best information available *Archæopteris* is not a true fern, but is a pteridosperm, showing that it had already developed the seed-bearing habit which would seemingly imply a very considerable developmental history. The huge fern trunks of *Caulopteris* show that the erect habit had gained marked headway.

As regards the place of origin of the Middle Devonian flora, White says: "Though eastern America has contributed most to our knowledge of this flora, it is probable that either the estuaries of northwestern Europe or the Arctic regions offered the conditions most favorable to its development. It extends both east and west in a high degree of unity." It has not, however, been found in the Southern Hemisphere.

On coming to the Upper Devonian we find the land flora well established and in full swing. It shows little evidence of climatic change from the Middle Devonian, but exhibits a number of new types such as *Pseudobornia,* a probable protocalimarian ancestor, several ferns, a probable ancestor of the Lycopodiales, and a *Lepidodendron*-like form as well as *Archæopteris* and trunks of *Cordaites* (*Dadoxylon*). In at

least two groups, one of which (the Cordaitales) probably formed forests, the seed-bearing habit was clearly established, though both failed to survive the Paleozoic.

The place of origin of this flora was apparently in eastern North America or the adjacent Arctic regions. It was, however, much more widely distributed, many of the same, or closely related forms, ranging from Pennsylvania and New York through eastern Canada, Ellesmereland, Spitzbergen, Bear Island, in the Arctic Ocean, the Don region of Russia, the British Islands, Belgium, and even reaching Queensland and Victoria. There is a noteworthy bed of coal of this age, 3½ feet in thickness, on Bear Island.

The interpretation of the climatic conditions under which the Devonian floras existed is beset with difficulties. So little is definitely known concerning the flora of the early Devonian that not much can be said of the probable climatic requirements, though it is difficult to understand how this flora, so newly emerged from the water and composed of thin, delicate-leaved types, could have endured except under uniform and moist conditions, and it seems a safe inference that the temperature must at least have been warm.

The climatic requirements of the Middle Devonian flora are somewhat difficult to interpret. Strange and harsh in aspect as this flora is, it has left little in linear descent and hence it is almost impossible to know the precise conditions under which it could have lived. The fact that it is so widely distributed over the Northern Hemisphere implies that the conditions were uniform and without obvious climatic zones. Its origin in or free migration over Arctic lands points at least to mild conditions. This view is supported by evidence of marine invertebrates. Schuchert says: "Warmer conditions again prevailed in the Northern Hemisphere early in Middle Devonic times, for coral reefs, limestones, and a highly varied marine life with pteropod accumulations were of wide distribution."

The Upper Devonian floras, however, are more easily and safely interpreted. Their wide distribution, which includes not only the Eastern and Western, but also the Northern and Southern Hemispheres, shows that the conditions of uniformity were still maintained, while the complete absence of growth rings in the woods shows the absence of severe changes in temperature or intervals of prolonged drought. Therefore the climate must have been equable and at least mild.

There is undoubted evidence of local and more or less circumscribed glaciation in the later stages of Devonian time, as, for example, in New

York, where it has been studied by Dr. John M. Clarke. There is no indication, however, that this affected the temperature of the oceans as reflected by marine life. Concerning this point Dr. Clarke writes me as follows: "Data from the invertebrate marine faunas are not merely negative. I think they are constructively positive in favor of absence of climatic zones; that is to say, in the main corroborative of your general proposition of a uniform undifferentiated climate."

Recently Mr. G. F. Matthew [7] has published a paper under the title, "Were there climatic zones in Devonian time?" in which he attempts to show that there are marked ecological differences between certain floras of the eastern United States and Canada, on which he predicates the climatic differences. But this is based on material that comes from beds of undoubted Carboniferous age which are compared with plants of undoubted Devonian age—the perpetuation of an error to which the author has long been wedded. No further discussion of this contention seems necessary.

Carboniferous floras.—In general.—During Carboniferous time plant life had become so abundant, so diversified, and so widely dispersed over the globe that a complete analysis of this flora in all its phases would demand far more space than is at command, hence only an outline of the salient facts bearing on the question of climatic conditions can be attempted. Although there have been some differences of interpretation there seems now to be substantial agreement on the essential points under discussion, namely, that there was an abundant supply of moisture, a wide distribution with little indication of climatic zones or marked botanical provinces, and that the climate was equable. This leaves open for consideration the fixation, if reasonably possible, of the probable temperature range.

Mississippian floras.—It might be presumed that in passing from the Devonian into the Mississippian there would be a gradual merging of plant forms, but in certain regions, at least, there is found to be a quite unexpectedly sharp difference in the floras. The early Mississippian was a time of sea expansion, and in many widely scattered parts of the world conditions became favorable for the formation of coal. This new flora, which, according to White,

"lived in the restricted basins of the early Mississippian consists of Triphyllopteris, the broad, large-pinnuled Aneimites, the linear type of Sphenopteria, Cyclostigma, Eokdalia, and the acuminate Lepidodendra chiefly of the *corrugatum* group. . . .

[7] G. F. Matthew: Trans. Roy. Soc. Canada, 3d ser., vol. 5, sec. 4, 1911, pp. 125-153.

"Either on account of land or marine barriers, or because the climatic conditions throughout the Northern Hemisphere may at the outset have been less uniform than in the preceding epoch, the different areas exhibit more or less distinct local floral differences. Thus in the Pocono of West Virginia and eastern Pennsylvania, where Triphyllopteris and the *corrugatum* type of Lepidodendron are almost without competition, the former achieved a remarkable differentiation far surpassing that known in any other area. In Nova Scotia, on the other hand, the Horton series, which I regard as practically contemporaneous with the Pocono, contains the same Lepidodendra, accompanied, however, by Aneimites instead of Triphyllopteris. In both the regions the formations are in close relations with the Upper Devonian. . . . All the genera mingle in Arctic Europe and Siberia, where Cyclostigma, probably of Arctic birth, has a good development."

In middle Mississippian time the earlier flora has been largely replaced by one that is very different in aspect. Here, says White, "We find a flora essentially consisting of Rhacopteris, Cardiopteris, Asterocalamites (= Bornia), with *Lepidodendron volkmannianum,* and *L. veltheimianum,* accompanied by a gradually increasing group of Sphenopterids."

This flora has a very wide range in the Old World. Originating or best known in western Europe, it extended westward into Siberia, and southeast probably through the Balkans and Persia to South Africa and Australia, and thence presumably by way of "Gondwana land" to Argentina, in the New World. The flora of this time in the Appalachian region is so little known that close comparisons are not yet possible.

The climate during middle Mississippian time was undoubtedly moderate and uniform. For although the members of this flora "do not attain the gigantic proportions nor the specific differentiation of their Carboniferous successors, yet the relative homogeneity and the great radial distribution of this flora argue for the absence of distinct climatic zones in the recent sense, while the apparent lack of annual rings, so far as the woods have been specially examined, is opposed to the idea of seasonal changes."

Knowledge of the upper Mississippian flora is still far from satisfactory, either as to composition or geographic range; hence only tentative conclusions can be drawn as to the probable climatic conditions under which it lived. From the fact that certain of the plant types exhibit somewhat depauperate, semi-coriaceous foliage, and the possible presence of growth rings in certain of the woods, White considers it as at least "provisionally admissible" that there were somewhat severer climatic conditions with more or less seasonal change.

Pennsylvania floras.—With the inauguration of Pennsylvania time

there came a remarkable change in the flora, which was perhaps due to—or in any event was accompanied by—renewed sea expansion. Many new types were either introduced or became dominant elements, such as Cheilanthes (Pseudopecopteris in part), Eremopteris, Lonchopteris, Megalopteris, Neuropteris, Bothrodendron, Ulodendron, Lepidophlois, etcetera.

The Pottsville and Allegheny time of North America is the approximate equivalent of the Westphalian or Muscovian of the Old World and witnessed the maximum development of such genera as Alethopteris, Neuropteris, Sphenopteris, etcetera. The climatic conditions must have been very uniform, for, while there are slight differences, this flora is found to have an almost world-wide range, in fact, as White says:

"The proportion of identical species is so large as to necessitate an extraordinary lack of barriers to the freest migration. The flora of the basin of Heraclea in Asia Minor lends itself readily to correlation, stage by stage, with three corresponding formations of the Pottsville in the Appalachian trough; also, of the 33 species reported by Zeillar in a collection from the Westphalian of the Djebel-Bechar region of Russia, 25 are present in the Pottsville of the Appalachian trough."

With the possible exception of the Jurassic it seems safe to say that at no time in the history of the world has there been such uniform conditions and consequent wide distribution of plant life as that of the Westphalian. Thus we find these practically identical assemblages of plants wide-spread over western Europe, central and eastern Asia, South Africa, eastern North America, and probably southern South America, or from latitude 58° N. to 25° S. and from longitude 110° E. to 100+° W.

At the close of Allegheny time and the incoming of Conemaugh or lower Stephanian time there was quite a marked change in the flora that may or may not have been due to climatic change. The gigantic Lepidodendra had almost disappeared and their places taken by a group of huge tree-ferns, known from the trunks as Psaronius and from the foliage as Pecopteris. This by some is interpreted as evidence of short dry seasons, which seems to be corroborative of the usual explanation of the origin of red beds, that is, as a result of distinct aridity. That there may have been some climatic modification is possible, but the mere presence of red beds can not be accepted as proof positive of aridity. On this point White [8] writes as follows:

"From the paleobotanical standpoint the widely current belief that aridity in the actual sense is to be assumed as causally and almost indispensably

[8] David White: The origin of coal. Bureau of Mines. Bull. 38, 1913, pp. 77, 78.

associated with red-bed deposition is not well founded. . . . However, in opposition to such a conclusion it must be noted that (*a*) the flora in the red beds has not been observed to differ very markedly from that in the regions of dark contemporaneous sediments, including coal; (*b*) the plants, though less varied, are not reduced in size, nor, possibly, in number; (*c*) coal, usually thin, to be sure, occurs in the midst of the red beds of the Conemaugh both in the eastern and the Rocky Mountain regions of America as well as in Europe, some of the coal being thick; (*d*) the evidence of seasonal growth ('annual rings') in the Conemaugh woods yet examined is slight, though the rings are a little more distinct than in the Allegheny woods; (*e*) the great calamitean growth appears unimpeded, though many of the giant species are provided with thick xylem and cortex; (*f*) the nearest living relatives of the Psaronii—the Marattiaceæ—are now exclusively tropical."

From these facts it is evident that the climate of this time was mild, practically free from frost, and still abundantly supplied with moisture as attested by the formation of peat.

In the upper Stephanian, which corresponds approximately to the Monongahela of the North America section, there was a revival of widespread uniformity of climatic conditions as indicated by the thick deposits of coal in many parts of the world. There is evidence in the plants that there was an absence or nearly complete absence alike of winter cold and at least prolonged seasons of drought. White concludes:

"On the whole the paleobotanical inferences are that during Monongahela time the climate was mild, probably subtropical, and nearly uniform over the greater part of the earth, as shown by the geographic distribution of the types that were able to extend in relative purity of association to identical species round the world from east to west, and from the latitude of England and Manchuria on the north to southeastern Africa on the south."

The testimony of the animal life of Carboniferous time as to climatic conditions is in substantial accord with that of the plants. Thus, Schuchert [9] says:

"The world-wide warm-water condition of the late Devonic seas of the Northern Hemisphere was continued into those of the Lower Carbonic. These latter seas were also replete with a varied marine life, among which the corals, crinids, blastids, echinids, bryozoans, brachiopods, and primitive sharks played the important rôles. Limestones were abundant and with the corals extended from the United States into Arctic Alaska. Reefs of Syringopora are reported in northern Finland at 67° 55′ N. . . . The marine faunas of Upper Carbonic time were fairly uniform in development, and many species had a wide distribution. . . . The very large insects of the Coal Measures tell the same climatic story. They were 'brutal robbers' and scavengers living in a tropical and subtropical climate, or at the very least in a mild climate

[9] Charles Schuchert: Smithsonian Inst., Ann. Rept., 1914, p. 294.

devoid of frosts. We therefore conclude that after Middle Devonian time the climate of the world was as a rule uniformly warm and more or less humid and remained so to the close of Upper Carbonic time."

Permian flora and its climatic significance.—The Permian flora presents many points of extreme interest. As already stated, during and at the close of Stephanian or Pennsylvanian Carboniferous time, the climate was uniform and mild—perhaps subtropical—and as a consequence the plants in practically identical assemblages were almost world-wide in distribution. Distinct botanical provinces are not known.

The incoming of the Permian inaugurated a series of events that produced a very profound modification of both climate and plant life—that is, the so-called "Permo-Carboniferous" glaciation. This glaciation, which occurred very early in the Permian and was probably of comparatively short duration, was principally about the Indian Ocean, and affected wide areas in India, South Africa, Australia, and eastern South America. This created two sharply marked botanical provinces—a northern and a southern province. In the northern province, which includes North America, Europe, and northern Asia, the Stephanian flora was able to continue with comparatively slight change, while in the south the original flora was mainly wiped out, and later succeeded by the so-called Gangamopteris or Glossopteris flora. The dominant types are Gangamopteris, Glossopteris Vertebraria, Neuropteridium, Noeggerathiopsis, Phyllotheca, Schizoneura, Ottokaria, etcetera. This is not strictly a glacial flora, though in some places, as in Australia, it is found in a higher inter-glacial epoch. It is persumed to have originated on a land mass (Gondwana Land) about the South Pole, and being a terrestrial flora there must have been practical land connection essential to its passage from these now widely separated areas—India, South Africa, Australia, and Brazil. The existence of this former land bridge is greatly strengthened by the finding of Glossopteris by the Scott Antarctic Expedition within 5 degrees of the South Pole.

During the time of actual glacial occupancy the climate was undoubtedly severe, and this influence extended over a wider area than was dominated by the Pleistocene glaciation. Thus, in certain woods found rather closely associated with these early boulder beds in Australia and South Africa, the growth rings are indicative of sharp seasonal changes, but it is evident that very soon after the close of glacial activity greatly ameliorated climatic conditions were soon restored, for woods in the higher beds, as in South America, show very little evidence of seasonal growth rings. This early restoration of favorable climatic conditions

is further shown by the fact that certain types characteristic of the northern province, such as Lepodendron, Lepidophlois, Sphenophyllum, etcetera, had penetrated the southern province, and Gangamopteris and Glossopteris had been able to reach the northern province in northern Russia.

White,[10] writing of these conditions, says:

> "The conditions which brought the new flora into being banished or exterminated the cosmopolitan or northern Permo-Carboniferous flora from the Gangamopteris province. The early return of a few of the hardier lycopodiaceous forms in Argentina, Brazil, and South Africa has already been mentioned. Most of the former plant population of the province died in exile, and only their posterity, especially among the Cladophleboid forms and the Araucarian, Ginkgodean, and Cycadalean gymnosperms were able to traverse the lost territory and contest the Gangamopteris occupation."

Triassic floras.—Rocks of Triassic age are known in many parts of the world and indicate two types of deposition, a fresh-water, marsh, or lagoon phase and a marine phase, the latter being by far the most extensive, which accounts for the meagerness of the flora. Owing to various considerations, physical and otherwise, concerning which there is not complete agreement, the lower portions of the Triassic afford but scanty plant remains, and it is not until we come to the upper portion, or Rhætic, that it can really be dignified as a flora. Our American Triassic is thought to belong largely to this portion.

The known plants of the Triassic are relatively few in number. In North America there are less than 150 species known, and the whole Triassic flora that has been recovered hardly exceeds 400 forms. The principal North American areas are in North Carolina, Virginia, and Pennsylvania, with relatively few in Maryland, New Jersey, Connecticut, and Massachusetts. In the West we have a doubtful plant or two from Wyoming, a considerable number from New Mexico, and the extensive fossil forests of Arizona. To the southward we have small collections from Sonora, from about the City of Mexico, and in the State of Oaxaca, also in Honduras, Chile, and western Argentina. In other parts of the world Triassic plants have been found in England, the east coast of Greenland and various islands in the Arctic Ocean, Spitzbergen, north Germany, southern Sweden, Italy, southwestern Spain, Persia, India, China, Tonkin, Japan, New South Wales, New Zealand, and South Africa. Many identical or closely related species are widely distributed.

The dominant plant types of the Paleozoic have largely disappeared.

[10] David White: Jour. Geology, vol. 15, 1907, p. 628.

The Lepidodendræ, Sigillariæ, Calamites, Cordaites, Sphænophyllæ, and Cycadofilices, so far as ascertained, have all disappeared, as well as a number of important genera of ferns—*Cheilanthes, Mariopteris, Megalopteris,* etcetera. The most notable survival of the Paleozoic flora is the so-called *Glossopteris* flora, which has been found with a few associated forms in Rhætic rocks at Tonkin, the Stromberg series of South Africa, in New South Wales, etcetera.

The Triassic flora consists essentially of ferns, equisetums, cycads, and conifers of many genera. A few forms, such as *Ginkgo, Cladophlepis, Thinnfeldia,* etcetera, had a small beginning in the Paleozoic and expanded in the Mesozoic into large groups.

It has often been said that the plants of the Triassic are depauperate and pinched in aspect, which is interpreted as indicating unfavorable environmental or climatic conditions, but the paleobotanical facts do not altogether bear out this contention. The earlier Triassic rocks are largely composed of so-called red beds that are interpreted by many geologists as an indication that they were laid down under conditions of aridity. As already pointed out, this view has been brought more or less in question of late, but whatever the result of the discussion the fact remains that they are largely barren of fossils, and hence our knowledge of the flora—especially the upland flora—of early Triassic time is limited. In the Upper Triassic rocks, however, there is every indication that climatic conditions were not unfavorable to vigorous plant growth. Thus in North Carolina, Virginia, and Arizona there are trunks of trees preserved, some of which are 8 feet in diameter and at least 120 feet long, while hundreds are from 2 to 4 feet in diameter. Many of the ferns are of very large size, indicating luxuriant growth, while *Equisteum* stems 4 to 5 inches in diameter are only approached by a single living South American species. The cycads and conifers are not more depauperate than those of subsequent horizons, nor do they compare unfavorably with the living representatives. The complete, or nearly complete, absence of growth rings in the tree-trunks indicate that there were no—or but slight—seasonal changes due to alternations of hot and cold or wet and dry periods. The accumulation of coal—in the Virginia area aggregating 30 to 40 feet in thickness—indicates long-continued swamp or marsh conditions, while the presence of tree-ferns seems to indicate, on the whole, a moist, warm, probably at least subtropical, climate.

Late Triassic and early Jurassic time.—During late Triassic time there was renewed crustal movement, as evidenced by volcanic activity

on a great scale in many parts of the world, but notably along the Pacific from central California to Alaska, and along the eastern Atlantic from Virginia to Nova Scotia. Schuchert says:

"Just how important this movement was and what effect it had upon the climate is not yet clear, but there is important organic evidence leading to the belief that the temperature was considerably reduced during latest Triassic and earliest Jurassic time."

He then points out that of the 1,000 or more species of Triassic ammonites not one is known to have survived into the Jurassic. The insects of the Liassic, of which group over 400 species are known, appear to have been quite uniformly dwarfed in size, which is interpreted by Handlirsch as indicating a cooling of the climate, perhaps to that of the present temperature of northern Europe between latitudes 46° and 55°.

From these data Schuchert concludes thus: "We therefore are seemingly warranted in concluding that the cooling of the climate in late Triassic and early Jurassic time was not local in character, but was rather of a general nature."

According to Schuchert the evidence offered by the marine invertebrates is in substantial agreement with that of the plants. The late Paleozoic forms were almost wholly replaced by a new assemblage, and certain forms, especially in Middle and late Triassic time, attained an extremely wide distribution. Schuchert says:

"We may therefore conclude that the rigid climate of the Permic had vanished even before the earliest of Triassic times, and that the climate of the latter period until near its close was again mild and uniform, though semi-arid or even arid the world over."

James Perrin Smith, after discussing the very wide range of certain limestones with thick coral reefs, interprets the evidence as indicating a "nearly uniform distribution of warm water over a great part of the globe" during Triassic time.

Jurassic floras.—In the lower portion of the Jurassic we find indications of a continuation of conditions which obtained in the upper portion of the Triassic. The distinctive Paleozoic elements had finally disappeared, and the Mesozoic life forms were in full swing, expanding in the middle and upper parts of the Jurassic into the abundant and wide-spread flora as we now know it. In fact, the Jurassic flora enjoyed in many respects the most marvelous distribution of any known flora, either living or fossil. It is known to range from Franz Josef Land, 82° N., to Hope Bay, Graham Land, 63° S., and from extreme western

Alaska entirely around the earth to eastern Australia, or through more than 155° of latitude and more than 230° of longitude. Throughout this vast, practically world-wide area, there is a remarkable uniformity of distribution that is not only in individual species widely spread, but considerable assemblages of species. Thus of the 17 species known from Cape Lisburne, Alaska, 8 are found in Amurland, eastern Siberia, 7 at Irkutsk, 6 near Kamonka, Government of Kharkow, and 4 each in Mongolia and Caucasia and Turkestan, while with the Island of Bornholm, Sweden, there are 4 species in common, and 4 species occur in the English beds, and 8 in Douglas County, Oregon. Of the 101 forms found in the Jurassic of Oregon and California, 47 have an outside range, there being 19 species common to eastern Siberia, 16 species at Yorkshire, England, 5 species at Hope Bay, Graham Land, and smaller numbers at widely scattered localities. Of the 23 species from Hope Bay that are known elsewhere, 4 species occur in India, 9 at Yorkshire, England, and, as already stated, 5 on our own Pacific coast.

This distribution shows conclusively that there was not only free communication between the Eastern and Western Hemispheres, but also between the Northern and Southern Hemispheres, and as none of the Jurassic plants is known to possess any peculiar mechanism for dispersal, it is apparently clear that there must have been a continuous or practically continuous land connection throughout this vast area. It is also evident that this wide distribution could only have been possible under very uniform climatic conditions. It remains to consider what those climatic conditions probably were.

The Jurassic flora that has been recovered to us numbers approximately 500 species, distributed among the following groups: Algales, Marchantiales ?, Filicales, Lycopodiales, Equisatales, Cycadales, Bennettitales, Ginkgoales, and Coniferales.

The algæ and liverworts are so few in number and in general so obscure and poorly preserved that little of value can be concluded regarding the environmental conditions under which they lived. The ferns are numerous in genera and species and usually abundant as individuals. A number of the fern genera have not yet been placed systematically, for the reason that their essential organs have not been found, but, on the other hand, there are a considerable proportion in which these features are known, and hence these can be interrogated with a great degree of certainty as to the presumed climatic requirements. Thus we have Osmundites, Todites, and Cladophlebis, that belong to the Osmundaceæ, the living members of which are largely tropical. Kluckia and Ruffordia

are referred to the Schizæaceæ, now almost wholly tropical. Gleichenites of the Gleicheniaceæ is mainly tropical. Laccopteris and Matonidium of the Matoniaceæ have the living representatives wholly tropical. Coniopteris and Dicksonia of the Cyatheaceæ are mainly tropical and subtropical. Dictyophyllum and Hausmannia of the family Dipteraceæ have the living forms wholly tropical.

Besides these there are other genera not so definitely placed, such as Polypodium, Scleropteris, Adiantites, Tæniopteris, Sagenopteris, Danæopsis, etcetera. These have been characterized on the basis of resemblance to the living forms (Polypodium, Adiantum, Tænia, Danæa, etcetera), and on this basis there is no reason to suppose they lived under conditions greatly unlike the habitat of the living analogues.

The Jurassic cycads are abundant in types as well as individuals, whence, of course, the designation of the Jurassic as the age of cycads. Approximately 25 genera of cycads are known from the Jurassic, including trunks so preserved as to exhibit all details of internal structure and reproduction, separate flowers (Williamsonia), and leaves, cones, and seeds of many types. The living cycads number 10 genera and about 80 species, and are essentially tropical in their present distribution, though a few forms are able to endure moderate cold or even frost.

The Ginkgoales is represented by a single genus (Ginkgo) and a single living species now confined to Japan, though there is some doubt as to its occurring in a wild state. It has, however, been grown for ornament in many mainly warm temperate parts of the world, although it can withstand several degrees of frost. Ginkgo is very abundant in the northern Jurassic and shows great diversity of leaf-forms, many of which have been given specific standing, though it is perhaps doubtful whether they should not be considered as representing a single polymorphous species.

The Coniferæ, although numbering twenty or more nominal genera, were not an especially dominant element in this flora, and a number of them are so fragmentary and badly preserved that their affinities can not be made out with satisfaction. All things considered, however, they appear to belong mainly to types that now find a congenial habitat in warm, not to say subtropical, lands.

Based on the above facts the following conclusion is reached regarding the probable climatic conditions during Jurassic time: The presence of luxuriant ferns, many of them tree-ferns, equisetums of large size, cycads, and conifers, the descendants of which are now found in southern lands, all point to a moist, warm, probably subtropical climate.

In 1883 Neumayr,[11] basing his deductions on a prolonged and intensive study of the ammonites, announced the conclusion that during Jurassic and Cretaceous time there were distinct climatic zones not unlike those now obtaining, that is, that there were clearly marked equatorial, temperate, and cool polar climates. Although this view obtained quite wide acceptance for a time, it is now very generally discredited, and it is held that his supposed temperature belts are only faunal realms. For instance, Dr. T. W. Stanton permits me to say that in his extensive studies on the distribution of Jurassic faunas from Texas to Alaska he has failed to find any indication of climatic zones, and Burckhardt[12] has had a similar experience in his studies of the Jurassic faunas of northern South America and Mexico, where he found a striking mixture of types that should appertain to two or more distinct climatic zones as interpreted by Neumayr.

Recently Gothan has described some supposed Jurassic woods from King Karl's Land (79° N.) which show very distinct growth rings, thus offering support, it is contended, of the existence of climatic zones such as advocated by Neumayr. It now appears, as pointed out by Burckhardt, that there is much doubt as to these woods having been correctly referred to the Jurassic. From the account of the geology of King Karl's Land as worked out by Nathorst, it is apparently established that the woods come from beds that are certainly younger than Neocomian and may indeed be Tertiary in age.

In discussing the faunal evidence as to Jurassic climate Schuchert[13] still adheres to the contention that there were three "clearly marked temperate zones," and then speaks as follows:

> "That the oceanic waters of Middle and (somewhat less so) Upper Jurassic times were warm throughout the greater part of the world is seen not only in the very great abundance of marine life—probably not less than 15,000 species are known in the Jurassic—but also in the far northern distribution of many ammonites, reef corals, and marine saurians. The Jurassic often abounds in reefs made by sponges, corals, and bryozoans. Jurassic corals occur 3,000 miles north of their present habitat. . . . The insects of this time were again large and abundant, indicating a warm climate—evidence in harmony with the plants."

Cretaceous floras.—Lower Cretaceous.—So far as regards the onmarching procession of plant life it is impossible to draw any very sharp

[11] M. Neumayr: Ueber Klmatische Zonen während der Jura und Kreidzeil. Denk. math. naturw., Classe d K. K. Akad. Wissensch., Wien, vol. 47, 1883.

[12] Carl Burckhardt: Sur le climat de l'epoque Jurassique. Mexico, 1907.

[13] Charles Schuchert: Smithsonian Inst., Ann. Rept., 1914, p. 300.

line between the Jurassic and the overlying Cretaceous; in fact, geologists are not altogether agreed as to just where the separation is to be made. By common consent, however, it is now pretty generally accepted that the line of the Lower Cretaceous shall be drawn at the base of the Wealden, that is, the Neocomian of the European time scale. Plant-bearing beds in this approximate position are abundant and very widespread, occurring in England (44 genera, 75 species), Belgium (20 genera, 30 species), France (7 genera, 12 species), Switzerland (9 genera, 12 species), Portugal (45 genera, 89 species), Germany (33 genera, 50 species), Saxony (20 genera, 30 species), South Africa (16 genera, 21 species), New Zealand (2 genera, 2 species), Japan (19 genera, 28 species), China (4 genera, 6 species), Spitzbergen (18 genera, 32 species), and Peru (6 genera, 8 species). Coming to North America we have the Patuxent formation (70 genera, 140 species) of the Potomac group, the Kootenai formation (41 genera, 82 species) of the northern Rocky Mountain region, the upper Knoxville (23 genera, 35 species) beds of California, and beds of approximate age on Queen Charlotte Islands (10 genera, 14 species).

Berry [14] has written as follows concerning these early Cretaceous floras:

"It is apparent that the dominant types of the late Jurassic floras continued without marked change throughout the older Cretaceous. These are the ferns, cycadophytes, and gymnosperms. We know little about the Thallophyta, the Bryophyta, or the Lycopodiales. The Equisetales had evidently dwindled to proportions strictly comparable to their present-day deployment. The more characteristic fern families of the older Mesozoic, such as the Marattiaceæ, are greatly reduced in importance, and the families Schizæaceæ, Gleicheniaceæ, Matoniaceæ, Osmundaceæ, and Dipteriaceæ, which are of great importance in the early part of the Lower Cretaceous, were destined to be overshadowed by the Polypodiaceæ before the close of the Cretaceous. Pteridospermæ are unknown, and it is within reason to suppose that this class was no longer represented in the flora of the world.

"The Cycadophytes of the early Cretaceous are essentially the familiar types of the late Jurassic. They are abundant in genera, species, and individuals, and are quite as dominant an element in the earlier Cretaceous as in the Rhætic and Jurassic floras. Before the close of the Cretaceous, however, they became extinct. The other gymnospermic types—the Ginkgoaceæ, Taxaceæ, and Pinaceæ—are all represented in the early Cretaceous floras."

It has been thought by some that the Angiospermæ, the now dominant modern type of vegetation, was introduced in the lowest Cretaceous (Patuxent) of eastern North America. Fontaine described three forms

[14] E. W. Berry: Maryland Geol. Survey, Lower Cretaceous, 1911, p. 147.

(Rogersia, Ficophyllum, Proteæphyllum) which he regarded as belonging to this class, but Berry has expressed doubt as to the correctness of this contention, and although they certainly simulate angiospermous plants, it is perhaps best under the circumstances to await further data before definitely accepting or rejecting them.

As to the probable climatic conditions under which the earliest Cretaceous plants existed, Berry says that the "floras are so different in every way from those of the present that it is unsafe to lean too strongly on the facts which may be deduced from the present climatic distribution of the sometimes remotely related representatives of these ancient types in the existing flora."

It is undoubtedly true that we must approach this matter with a measure of caution, yet a number of undeniable facts seem established. The presence of these floras in Peru, 15° south of the Equator, and in Greenland and Spitzbergen, 78° north, as well as their wide range over both hemispheres, points to relatively uniform and equable conditions, whatever the temperature may have been. The petrified woods show relatively slight seasonal changes, that is, the active growth-ring is very wide and composed of large cellular elements, while the area of restricted growth is very narrow and irregular, and "is as readily explained by a dry season as by a cold winter." Another important fact is that there are no certainly known deciduous forms. The size and vigorous growth of most of the vegetation indicates an abundant supply of moisture, well distributed throughout most of the annual cycle. Further, if we compare the several types of plants with their obviously nearest living relatives, it seems a fairly reasonable assumption that their temperature requirements could not have been greatly different. Therefore, I feel justified in holding that the climate of early Cretaceous time was equable, moist, and fairly warm, that is; at least very warm temperate.

The Barremian of the European scale is believed to be represented in eastern North America by the Arundel formation, which contains a small flora mainly of ferns, cycads, and conifers, but with several of the doubtful angiospermous types mentioned as occurring in the Patuxent formation. Of similar age is the so-called Kome flora of Greenland, which includes 88 species, over 40 of which are ferns, while there are 18 conifers, 11 cycads, and 3 each in Ginkgo and Equisteum. There are also two undoubted dicotyledons, though there is grave doubt as to their having come from these beds. In the Eastern Hemisphere there has been noted a large flora (23 genera, 45 species) from Portugal, and small floras from England (7 genera, 17 species), France (8 genera, 9

species), Austria-Hungary (22 genera, 29 species), and Eurasia (18 genera, 23 species). These floras are made up mainly of ferns, cycads, and conifers, no dicotyledons being known to be present.

The Aptian is believed to be represented in North America by the Glen Rose limestone of Texas, with 16 genera and 25 nominal species, of which 8 are cycads, 11 conifers, and 1 fern, and by the Lakota sandstone of the Black Hills region, which includes 21 genera and 59 species, there being 13 ferns, 33 cycads, and 8 conifers; neither includes dicotyledons.

In Europe the Aptian is known from France (2 genera, 2 species), Germany (9 genera, 12 species), Italy (13 species, 1 genus of cycads), and Portugal (21 genera, 25 species), the cycads predominating and angiosperms absent.

The uppermost portion of the Lower Cretaceous, the Albian of Europe, witnessed—at least in extenso—the formal establishment of the since dominant angiospermous types of vegetation and the beginning of the decline of ferns, cycads, and conifers. The Patapsco formation of Maryland and Virginia has afforded a flora of not less than 60 species, of which number 25 are undoubted angiosperms. These are so diversified in type and so highly organized as to suggest strongly a long previous period of development, but we do not yet know when or just where the evolution took place. They began immediately the conquest of the earth, and the Fuson formation of the Black Hills region, though still having a preponderance of ferns, cycads, and conifers, included some half dozen angiosperms.

In beds of Albian age in Portugal there is a considerable flora (36 genera, 66 species) which embraces 20 ferns, 6 cycads, 18 gymnosperms, and 22 angiosperms, a number of which are identical with species in the Patapsco formation. The Upper Albion of Portugal contains a flora of 15 genera and 26 species, but has no ferns or cycads and but a single conifer, the remainder being all angiosperms. Small floras of Albian age are known from England (3 genera, 8 species) and France (17 genera, 35 species), but they are without known angiosperms.

As regards the climatic conditions that may fairly be presumed to have obtained during the upper part of the Lower Cretaceous, I can see no reason for supposing that it was greatly different from that already indicated for the lowest Cretaceous, namely, equability, abundant moisture well distributed throughout the year, and a temperature that was at least warm temperate.

Upper Cretaceous.—By the beginning of Upper Cretaceous time, assuming that the Albian is correctly placed in the Lower Cretaceous, though this view is not always accepted, the angiosperms had assumed dominance, and the ferns, cycads, and conifers had fallen to the subordinate position they have since held. In the earliest members of the Upper Cretaceous the angiosperms had already been differentiated into the two groups of monocotyledons and dicotyledons. These new types spread so rapidly and so widely that it will be impossible fully to consider the great number of plant-bearing beds in the many parts of the world.

In certain particulars the most important of these Upper Cretaceous floras are those of the Greenland, which occur mainly on the Nugsuak Peninsula from latitude 69° 15′ to 72° 15′ N. This, it will be noted, is well within the Arctic Circle. The oldest flora—that of the Atane beds—comprises 88 genera and 181 species, 70 per cent of which are dicotyledons. Overlying this is a thick series of beds—the Patoot beds—the upper portion of which may show transition into the Tertiary. The Patoot flora includes 72 genera and about 122 species, 80 of which are dicotyledons.

Plant-bearing beds, similar if not indeed identical in age with the Atane beds, are found in the Raritan formation, which extends along the Atlantic Coastal Plain from Massachusetts to Maryland. The Raritan flora embraces 102 genera and 220 species, 150 of which are dicotyledons. Forty-seven of the Raritan species occur in the Atane beds.

Immediately overlying the Raritan and with much the same areal disposition is the Magothy formation, with 123 genera and 275 species, 200 of which are dicotyledons. Of approximately similar age is the Dakota flora, which includes 125 genera and over 500 species. In this connection it is of great interest to note that a small but unmistakable Dakota flora has been found by Kurtz in north-central Argentina, showing that this flora spread south a distance of 5,000 miles, crossing the Equator and a land bridge that must have connected North and South America at this time.

In the Atlantic Coastal Plain and Gulf regions there are a number of important floras in the approximate position of the Magothy and Dakota floras, altogether aggregating several hundred species, largely dicotyledons. These floras occur in the Black Creek, Eutaw, Tuscaloosa, and Woodbine formations. In the Rocky Mountain region the Upper Cretaceous is more or less abundantly plant-bearing, one of the most interesting being that from the Frontier formation (of the Colorado group) of western Wyoming. Although consisting mainly of dicoty-

ledons, it concludes some peculiar ferns that find their closest relationship with species now living in the Pacific islands. The Montana group has afforded several small floras, including that of the Mesaverde formation (80 ± species), the Vermejo formation (108 species, 51 genera), the Fruitland and Kirtland formations (40 species, 20 genera), and the Fox Hills sandstone (14 species, 12 genera). The Laramie formation as at present accepted has a flora of 129 species belonging to 53 genera.

In the Canadian provinces there are small Upper Cretaceous floras, as that of the Mill Creek series (25 species), the Belly River (about 150 species), and the northern part of Vancouver Island (81 species).

With the exception of the Dakota flora already mentioned floras of Upper Cretaceous age are practically unknown in South America and Antarctica. Australia has a somewhat doubtful flora referred to this age (61 species), and New Zealand a still smaller one (36 species). Asia, during Upper Cretaceous time, was receiving mainly marine deposits, and hence few plants are known, the most notable being from Japan (23 species). Africa has also very few plant beds of this age.

Turning now to Europe, only briefest mention can be made of the Upper Cretaceous plant deposits. Thus, only 7 species are recorded from Scandinavia and none from England, which received only marine deposits. France fared a little better, having small floras from the Cenomanian of Anjon, the Argonne, and the Ile d'Aix (15 ± species), the Turonian of Bagnols and Mède (48 species), the Eschmerian of Beausset near Tulon (10 species), and the Atrurian of Foveau (19 species). Portugal has Cenomanian, Turonian, and Senonian floras aggregating about 80 species. The Italian flora is almost negligible (11 species), while the German and Austrian-Hungarian floras are very large. Thus, from the basal Campanian, in the vicinity of Aachen (Aix-la-Chapelle), about 150 species are known, over 80 species (Cenomanian) from Niedershœna, 25 species or more from near Dresden, and over 70 species from Saxony. From the Perucer beds (Cenomanian) of Bohemia no less than 184 species have been described, while from Moravia there are considerable floras known.

Climate of Upper Cretaceous time.—Before discussing the probable climatic conditions that seem to be indicated for Upper Cretaceous time, a word may be said as to the presumed place of origin of the dicotyledonous floras that had spread so widely and almost coincident with the dawn of the Upper Cratecous. Although, as Berry has well said, the time has not come for a thoroughly satisfactory discussion of the origin and migration of this great flora, it bursts upon our attention with such

suddenness as to suggest that it must have had a long anterior period of development, perhaps on some great land-mass that was not then receiving sedimentation, or is still unexplored. Berry[15] continues:

"It has been assumed, and it is certainly the most attractive hypothesis, that the origin of the dicotyledons was in high latitudes from which region they spread southward over the continents of the Northern Hemisphere in successive waves of migration. There is considerable evidence in support of this theory, but the unexplored Cretaceous sediments of the great continent of Asia and most of the lands in the Southern Hemisphere invalidates too hasty generalizations. The land-mass of Asia with free land communication during Middle Cretaceous time to the northward, southward, eastward, and westward, has not received the consideration which it merits as a center of distribution, nor have the American tropics received much attention. . . . This one conclusion seems warranted, that the origin and initial radiation of dicotyledonous floras took place somewhere in the great massed land areas of the Northern Hemisphere."

Although there are marked differences between many of the more or less widely separated floras that are believed to be in approximately similar stratigraphic position, there are, nevertheless, so many species held in common as to lead to the inevitable conclusion that climatic zones such as now exist did not obtain during Upper Cretaceous time. We find, for instance, that the Atane flora ranged from Greenland along the Atlantic Coastal Plain and Gulf region to Texas with but little change, and the Dakota flora spread with practically no change from Kansas to Argentina. In fact, as Berry says, "they cross the equator unchanged in both the Eastern and Western Hemispheres."

The inference to be drawn from the above facts is that during Upper Cretaceous time the temperature conditions were very uniform and equable over the greater part of the earth's surface, extending from at least 72° N. in Greenland to at least 60° S. in Argentina, with the probability that it was practically world-wide.

The moisture conditions may next be considered. The study of these floras reveals very little evidence of deciduous habits, which implies an uninterrupted growing season and an abundant, or at least an adequate, supply of moisture, well distributed throughout the year. An example in the existing floras is shown by the warm temperate rain-forests of many parts of the world. The existence of an abundance of moisture is also further shown by the presence of very considerable deposits of coal, especially in the Rocky Mountain region, which implies wide-spread and long-continued swamp or marsh conditions.

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[15] E. W. Berry: Maryland Geol. Survey, Upper Cretaceous, 1916, p. 311.

We may now attempt an interpretation of probable temperature conditions during Upper Cretaceous time. To begin with Greenland, it of course needs no argument to prove that the climatic conditions there were very different from those obtaining during and since Pleistocene time. The following Atane genera are given with their present-day distribution and climatic requirements: Artocarpus (bread-fruit tree) now confined to the Old World and within 20° of the Equator. Ficus, a vast tropical genus with a few species ranging into warm temperate regions. Cinnamomum and Laurus, small genera in the cool parts of the tropics. Pseudocycas, one species of which at least is closely related to the tropical *Cycas revoluta.* Aralia has about 27 living species in the temperate and warm parts of America and Asia. Panax, a small genus of eastern North America and central and eastern Asia. Pistia, a monotypic genus very widely distributed in the tropics and subtropics of both hemispheres. Cyathea (tree-ferns) embraces 100 species widely disseminated in the tropical and subtropical countries, extending in New Zealand 40° S., but not occurring above the northern tropics. Gleichenia, represented in the Atane flora by six species and a profusion of individuals, is confined as now restricted by pteridologists to the tropics and subtropics of the Old World. Widdringtonites, so named from its resemblance to Widdringtonia, a genus of four species now living in South Africa and Madagascar.

There are other genera in the Atane flora whose living representatives have a more or less extensive representation in temperate regions, some of which also have representatives in warm temperate and even in subtropical regions. These are Acer, Asplenium, Cassia, Cissites, Diospyros, Hedera, Ilex, Magnolia, Myrsine, Palaurus, Pinus, Pteris, Quercus, Sapindus, Selaginella, etcetera.

From the above presentation of facts it seems safe to conclude that the climate of Greenland during Atane time could not have been cooler than warm temperate, and when we consider the presence of bread-fruit trees, figs, cinnamon trees, tree-ferns, etcetera, it might well have been at least subtropical. Heer concluded the Atane flora probably flourished in a climate with a mean annual temperature of 19-20° C. Some students have placed the temperature higher than this, and others have placed it lower.

It will be impossible, indeed perhaps unnecessary, in the space available to make as complete an analysis of the other Upper Cretaceous floras, but a few notable conditions may be pointed out. There is nothing, so far as I can interpret it, in the floras of eastern North

America that militates fatally against the conclusion that they required at least a warm temperate and possibly a subtropical climate. Turning to the Rocky Mountain region we may select the Frontier formation (of Colorado age), concerning which Knowlton [16] has published as follows:

"The climate during Frontier time appears to have been tropical or subtropical, as is shown in a number of ways. Thus, one of the most abundant of the ferns (Tapeinidium) was indeterminate in growth, a condition that could survive to the extent here indicated only in the absence of frosts. The most abundant elements in this flora are the ferns, . . . and all call for a tropical or subtropical habitat. . . . The wax-berry (Myrica), the oak (Quercus), and the willow (Salix), might not be out of place in a tropical region, but the figs (Ficus) and the cinnamon trees (Cinnamomum) certainly required a tropical or subtropical location."

The flora of the Vermejo formation (of Montana age) includes breadfruit trees, 16 species of figs, fan palms of gigantic size as well as types indicating a more temperate condition, but when viewed as a whole the following conclusion was reached: [17]

"From the abundance and proportions of the plant types it may be presumed that there was an abundance of moisture, from the absence of marked growth rings that there was no sharp differentiation of seasons, and from the general facies of the whole flora that the climate was warm temperate and perhaps even subtropical."

Tertiary floras.—Origin of herbaceous types of vegetation.—Before discussing the various Tertiary floras it is important to call attention to a very profound change that came about in plant life at this time—namely, the evolution of herbaceous types of vegetation. During the whole of the Cretaceous and at least the earlier part of the Tertiary herbs are practically unknown, whereas in the present flora they vastly outnumber the woody types in all the cooler parts of the world. It seems to be generally accepted that the herbs have descended from woody plants in direct response to increasing refrigeration during Tertiary time. Dr. E. W. Sinnott [18] has recently published a very important article on "The evolution of herbs," from which I venture to quote the following:

"These facts—that woody plants are more ancient than herbs is shown by evidence from fossils, from natural relationships and from anatomy; that herbs are now dominant and woody plants few in species in regions subject to low winter temperatures, and *vice versa;* that regions which have been isolated from the north temperate land-mass possess few herbs in the ancient

[16] F. H. Knowlton: U. S. Geol. Survey Prof. Paper 108, 1917, p. 79.
[17] F. H. Knowlton: U. S. Geol. Survey Prof. Paper 101, 1917, p. 235.
[18] E. W. Sinnott: Science, new ser., vol. 44, 1916, p. 295.

portion of their floras, and that the northern continents supported at no very ancient day a much more varied woody vegetation than at present—all suggest the conclusion that a large part, at least, of our modern herbaceous vegetation originated in the north temperate zone in response to the progressive refrigeration of climate which we know to have taken place there during the Tertiary.

"The great advantages conferred by the possession of an herbaceous habit of growth in a region subject to low winter temperatures are obvious, for such plants are able to complete their cycles and to mature seed in the warm summer months and can then survive the cold of winter in the form of resistant seeds or by hibernating underground. Only the hardier types can maintain permanent aerial stems under these conditions. The more delicate woody families have either been exterminated outright in temperate regions or have survived only by assuming an herbaceous habit and thus flourishing in that part of the year which is free from frost. As might be expected if low temperature has indeed been the determining factor in the development of herbs, most of those families which are well able to survive cold, as trees or shrubs, and which form the bulk of the woody vegetation of the north temperate zone—the willows, birches, oaks, beeches, walnuts, hickories, wax myrtles, elms, hollies, heaths, buckthorns, lindens, planes, sumacs, cornels, and viburnums—are families which are almost entirely without herbaceous members. Being hardy, they have not been forced to adopt the herbaceous habit.

"As to the details of this change in growth habit we can not of course be sure, but in those forms which it did not kill outright the increasing cold probably effected a gradual reduction in size and an attendant shortening of the time necessary to reach maturity, until very dwarf forms were produced which were able to develop from seed to seed in a year or two, and which could be killed back to the ground every winter—in short, perennial herbs. The herbaceous vegetation in arctic and alpine regions today is still composed almost entirely of such plants."

Interesting statistics are given by Sinnott to show this decrease of herbaceous types from arctic and alpine regions to the heart of the tropics. Thus, in Ellesmereland the percentage of herbs is 92, Switzerland 91, Iceland 90, Great Britain 89, Rocky Mountains 87, northern United States 78, Japan 57, tropical Africa 42, Ceylon 37, Java 27, Brazil 26, Lowlands of the Amazon Valley 12 per cent.

The composition and distribution of Cretaceous and Tertiary floras undoubtedly lend support—shall I say proof—to this view regarding the origin of herbaceous types. Their absence during Cretaceous and much of Tertiary time had long ago been noted, and their absence from these floras was explained on the ground of their usually small size, delicate structure, and generally non-deciduous leaves, but this explanation of their descent from woody types explains much that was before obscure.

Eocene floras and their probable climatic requirements.—Although a

very considerable number of modern plant types were undoubtedly established by the end of Cretaceous time, there are nevertheless notable differences to be observed in the composition of the floras of the Cretaceous and Tertiary. Much of the sharpness of this distinction has in the past been lost or obscured by the vicarious placing of the line between Cretaceous and Tertiary. This has been especially true in North America, where the placing of such important plant-bearing units as the Raton, Dawson, Denver, Lance, etcetera, in the Cretaceous has had unfortunate effects; but now, supported by important diastrophic data, it seems to be pretty generally conceded that they properly belong in the Tertiary. As bearing on the distinctness of Cretaceous and Tertiary floras, it may be stated that approximately 40 per cent of the genera in existence in the Cretaceous had become extinct at the close of that time.

North America is fairly rich in Eocene floras, especially in the Gulf region, Rocky Mountain region, and in the northern Pacific coast region. The oldest of the plant-bearing units in the Gulf region is that of the Midway formation, but the known forms are so few that they become negligible in the present connection. Above the Midway is a thick series of sediments known as the Wilcox group, which has a flora of 134 genera and over 330 species. The Wilcox flora has been fully elaborated by Berry,[19] who points out that it is "overwhelmingly that of a strand flora, of which some of the elements indicate that they grew on the sandy beaches, others in muddy tidal flats, others between or behind dunes or beach ridges, and others in estuary bayous or marshes. None of the forms can certainly be considered as inland or upland types."

Berry says further:

> "It may be noted that all of the Wilcox plants, almost without exception, are plants whose modern representatives inhabit the warmer parts of the earth. There is not a single strictly temperate type in the whole assemblage. . . . Compared with recent costal floras, it is at once apparent that its affinities are entirely with those of tropical and subtropical America. . . . It is obvious that the flora could not have existed if the region was ever visited by frost, and temperatures appear to have been like those found today on the Florida Keys."

In other words, a subtropical rain forest.

Of approximately the same age as the Wilcox, or possibly slightly older, is the flora of the Raton formation of the Raton Mesa region of New Mexico and Colorado. This flora contains 148 species, over 40 of which are identical or closely related to those of the Wilcox flora. One

[19] E. W. Berry: Proc. Am. Philos. Soc., vol. 53, 1914, p. 135; U. S. Geol. Survey Prof. Paper 91, 1916, p. 74.

of the most conspicuous and dominant elements in this flora was the palms, of which there were at least 6 genera and 9 species, some of them being exceedingly abundant in individuals. The 15 species of figs (*Ficus*), as well as 3 bread-fruit trees (*Artocarpus*), undoubtedly argue for a warm climate. Magnolias were also abundant and likewise predicate a warm climate, as do the laurels (*Laurus*), cinnamons (*Cinnamomum*), and related forms. The presence of numerous coal veins, as well as the character and luxuriance of the vegetation, indicates that moisture was abundant, and the known distribution and requirements of the living representatives of the Raton flora make it more than probable that the climate was at least warm temperate.

Correlated with the last is the Denver formation of northern Colorado, with a flora of approximately 200 species. The physical conditions under which it grew were apparently the same as for the Raton flora.

The flora of the Lance formation of Wyoming and the Dakotas has not been thoroughly studied, though so far as worked out it is so closely related to that of the Fort Union that for present purposes they may be considered together. The Fort Union occupies a vast area from Wyoming and the Dakotas, Montana, and the central Canadian provinces to the valley of the Mackenzie River. It has a flora of some 500 species. Although there are palms of large size in the lower portions of the formation, the bulk of the flora is made up of sequoias, cedars, yews, grasses, sedges, oaks, willows, poplars in great abundance and variety, hazelnuts, walnuts, elms, sycamores in profusion, maples, viburnums in great variety, and a few somewhat doubtful figs. This flora, which is closely similar to that in north Greenland, undoubtedly approached from the north. Notwithstanding the presence of palms, which, however, occur in the lower parts of the beds, the composition of this flora seems to indicate that temperatures were considerably lower than for those Eocene floras already reviewed—in fact, that it was temperate, perhaps what would be called cool temperate.

In the northern Pacific coast region there are a number of Eocene floras, among them that of the Swauk, which occurs just east of the Cascade Mountains in Washington. This large flora is different from any other yet made known in this country, and consists largely of types that are for the most part found in Central and South America, among them being fan-palms 6 feet in diameter and in layers sometimes a foot in thickness. This shows that the palms were not sporadic or occasional, and indicates, as do many of the other things, that the climate was mild, probably even subtropical. The overlying Roslyn formation contains a

flora that is almost entirely different from that of the Swauk and, lacking the presence of palms, was apparently slightly cooler than the temperature obtaining during the deposition of the underlying beds.

At Cherry Creek, Oregon, there occurs a small lower Eocene flora of 20 species in beds of the lower part of the Clarno formation. It is a warm temperate flora. Almost the only known middle Eocene flora found on this continent is that of the Green River formation of western Wyoming. It has a flora of about 80 species, mainly of very modern types, among them such as Acrostichium, Lygodium, Mannicaria, Musophyllum, Sapindus, Zizyphus, etcetera, which indicate a climate considerably warmer than the Fort Union, for instance.

Another small flora of approximate middle Eocene age is the Claiborne flora of Georgia recently elaborated by Berry.[20] It comprises only 17 species, but embraces such a proportion of absolutely determined forms that there is believed to be little probability of error in interpreting their requirements. It is distinctly a coast or strand assemblage, and Berry concludes that it indicates a condition approximated by the subtropical or warm temperate rain forests of the present day. Being in proximity to the warm Eocene ocean currents, it must have been uniformly humid, and the temperature "would have to be uniform rather than hot, . . . for any degree of winter cold would have been fatal."

In Alaska we have the upper Eocene Kenai formation, which has afforded a rich flora of oaks, poplars, willows, hazels, walnuts, magnolias, horse-chestnuts, and maples, together with pines, spruces, cedars, and sequoias. This flora is also found in British Columbia, and is abundantly represented in Greenland, Iceland, and Spitsbergen, showing that it was of wide extent in northern latitudes. It is distinctly a warm temperate flora.

Turning now to the Old World, we find a number of important Eocene floras, though not all have yet been worked up to the point where their data can be made full use of in interpreting climatic conditions. Thus, the basal Eocene, the so-called Paleocene of Schimper, or the Montian and Thanetian stages of subsequent writers contains two important floras in northern France and Belgium. That of the plastic clays of Trieu de Leval (Hinaut), Belgium, as described by Marty, comprises only about 20 species and is thought to find its closest resemblance in the equatorial region of South America. The flora from the travertines of Seganne, France, elaborated by Saporta, is larger (87 species) and is apparently a temperate or warm temperate flora.

[20] E. W. Berry: U. S. Geol. Survey Prof. Paper 94, 1914, p. 129.

The Lower Eocene contains a number of important but mainly unstudied English deposits, and at a slightly higher position the extensive deposits of Alum Bay and the London Clay in England. Our knowledge of the flora of these two localities is confined to a list of the names, but the plants have never been described or figured. The Alum Bay flora comprises 116 genera, 273 species, and that from the Isle of Sheppy 72 genera and 198 species. The plants as thus made known appear to indicate a much warmer climate than the floras of the French and Belgian deposits just mentioned; in fact, Gardner regards it as tropical. If these plants have been correctly identified—and a large proportion of them are seeds and fruits that are susceptible of close study—it is difficult to see how the climate could have been cooler than subtropical at least.

A time of great sea extension marked the Middle Eocene in Europe, and it is only in the upper beds, such, for instance, as the *calcaire grossier supérieur* of the Paris Basin, that plants are preserved. A small florule from the last-mentioned beds has been described by Bureau, including Pandanus, Flabellaria, Sabal, Palmacites, Yucca, and Nuphar. These indicate that the climate was still warm, probably nearly tropical.

In the southern part of England the Bogshot sands and the Bournemouth clays, as well as the beds of Antrim and Mull, contain a very large, beautifully preserved flora, but it is mostly undescribed. Gardner has worked up the ferns and conifers, among them being the genera Acrostichum, Anemia, Gleichenia, Meniphyllum, Araucaria, Cupressus, Podocarpus, and Sequoia. Certain genera of monocotyledons are indicated, such as Phœnix, Calamus, and Nipa. These seem to indicate that the climate must still have been warm and moist.

Of approximately the same age as those above mentioned are the plant beds of Monte Bolca, Italy. A warm, probably subtropical, climate is indicated by the presence of numerous and large palms.

One of the largest and best known of European and Eocene floras is that from Aix, in Provence, France, described by Saporta, which comprises over 500 species. It includes fungi, algæ (Chara), hepatics, mosses, ferns, conifers of many genera, grasses, sedges (Carex), palms (5 genera, 12 species), Smilax, irises, cat-tails, wax-berries, alders, birches, oaks, elms, figs, laurels (5 genera, 26 species), Daphne, Proteoides, composites, Olea, ashes, Catalpa, Myrsine, Bumelia, persimmons, Andromeda, Vaccimium, Aralia, buttercups, water-lilies, magnolias, barberry, maples, Sapindus, bittersweets, buckthorns, sumacs, Ailanthus, clover (Trifolium), and a great number of genera and species of leguminous types.

Saporta makes elaborate comparisons of the Aix flora with that now living in various parts of the world, notably Asia and Africa, and concludes that the climate was tropical or subtropical.

Other large floras of about the same age as the last are known from Häring, in the Tyrol, and several localities in Dalmatia; but they need not be further considered here.

Miocene floras and their climatic requirements.—The known Miocene floras of North America are relatively unimportant, although in the aggregate probably somewhat over 500 species have been indicated. The deposits occur in often small isolated basins that in some cases are separated by hundreds of miles. Thus, the only flora of any importance in the entire area east of the Rocky Mountains is at Brandon, Vermont, where there are small pocket-like deposits of lignite in the midst of ancient crystalline rocks. These have yielded large numbers of fruits and seeds and a very few poorly preserved leaves. Upward of 150 nominal species have been described, many of which are referred to form genera, such as Bicarpellites, Cucumites, Tricarpellites, Brandonia, etcetera, with a few suggesting affinity to modern genera, as Nyssites, Hicoria, Juglandites, etcetera. There is so much uncertainty regarding the botanical allocation of these forms that it is impossible to draw very satisfactory or convincing conclusions as to the climatic conditions under which they grew, though obviously they must have been quite different from present conditions. However, as certain of the lignites studied show well marked growth rings, it is apparent that there must have been well defined seasonal changes of some sort.

At Florissant, Colorado, also in the midst of older crystalline rocks, there are small lake-bed deposits which have afforded vast quantities of plant and insect material that is largely in an admirable state of preservation. About 1,000 species of insects and upward of 200 species of plants have been described. According to Scudder, the insects show certain tropical affinities, but also embrace representatives of forms now living in the vicinity. Much the same can be said of the plants; for, though the general facies of the flora is abundantly different, there are a number of generic types that are now living in the region. Certain important types show relationship with the flora of the Southern States and the West Indies and indicate that the climate was considerably warmer than the present one. Large silicified trunks of Sequoia are found in these beds, and, as they show well defined growth rings, it is an indication that there were marked seasonal changes of temperature. It is also evident that there was a greater degree of moisture, and altogether it

seems a safe assumption that the climate was at least temperate. It is important to note that a considerable number of unmistakable harbaceous types were present.

There is a small Upper Miocene flora found at Elko, Nevada, that is apparently of the same age as the Florissant lake beds, but it is too small to be of much value in the present connection. In approximately the same position is a small florule of 14 species from Esmeralda County, Nevada. It indicates a higher degree of moisture than at present obtaining and altogether a climate probably like that of the Southern States. In California the auriferous gravels have yielded a flora of some 125 species, many of them of very modern appearance, such as Acer, Artocarpus, Magnolia, Persea, Quercus, Castanopsis, Zizyphus, etcetera. On account of their obvious affinity with the living flora, they were at first referred to the Pliocene by Lesquereux, but later they came to be regarded as Middle Miocene. This flora is much in need of critical revision, and latest stratigraphic studies seem to indicate that the auriferous gravel phase may possibly have begun in the uppermost Eocene and continued on well into the Miocene. In the John Day Basin of Oregon there is the Middle Miocene Mascall flora of about 80 forms. It includes Sequoia, Glyptostrobus, Taxodium, Populus, Salix, Juglans, Hicoria, Quercus, Ulmus, Planera, Magnolia, Laurus, Platanus, Rhus, Acer, Sapindus, etcetera, and altogether indicates at least a temperate climate. In the Yellowstone National Park there are two small Miocene floras that have much the same facies as that last considered and point to much the same conclusion regarding its climatic indications. The numerous fossil trees so prominent in the park all show strongly defined growth rings. To the north, in the Canadian provinces, Dawson has signalized the Upper Miocene flora of the Similkameen Valley, a flora of some 25 forms, all indicating temperate conditions.

In the Old World many and widely scattered Miocene floras have been made known, the most extensive and most completely exploited being that of Switzerland, as described by Oswald Heer.[21] This flora includes some 920 species, of which number 114 are so-called flowerless plants and 806 are flowering plants. Of the latter, 291 are species of trees and 242 are shrubs, or 533 species of woody plants. The herbaceous flowering plants number 164 species. On the basis of certain proportions between the several groups of plants, Heer concludes that the full Miocene flora of Switzerland could hardly have been less than 3,000 species, which is far in excess of the number now living there. Associated with the plants

[21] Oswald Heer: Flora Tertiaria Helvetiæ, vol. 1, 1854; vol. 2, 1856; vol. 3, 1859.

were numerous species of insects, and from their combined study Heer was able to work out many interesting conclusions, such as the succession of seasons and, above all, of the climatic requirements. Concerning the climate, Heer[22] wrote as follows:

"In the Upper Miocene (of Œningen) the tropical types constitute only 7 per cent of the total number of vascular plants, whilst in the Lower Miocene (Aquitanian) the tropical types are 15 per cent of the whole, which shows that a decrease of temperature must have taken place, although the frequent occurrence of the camphor- and cinnamon-trees, and the appearance of feather- and fan-palms, demonstrate that Œningen still enjoyed a warm climate.

"If we sum up all the data furnished by the flora, we are led to the conclusion that the Swiss Lower Miocene district possessed a climate similar to that now prevailing in Louisiana, the Canaries, North Africa, and South China, namely, a climate with a mean annual temperature of 20–21° C. (68'–69.8° F.), and that the Swiss Upper Miocene district had a climate resembling that of Madeira, Malaga, and the south of Sicily, southern Japan, and New Georgia, with an annual temperature of 18–19° C. (64–66.2° F.)."

Pliocene floras and their climatic requirements.—The Pliocene flora of North America is almost a negligible quantity, and is far too small to be of value in the present connection. It consists of a small florule, thought to be of this age, from the Falls of the Columbia River. It includes species in the genera Woodwardia, Sassafras, Sterculia, etcetera, all being extinct, though very closely related to living forms.

A florule of 20 species, all living today in the Coast Ranges of California, has been described by Hannibal[23] from the Santa Clara formation of the Coast Ranges of California. Concerning it the author says:

"This flora agrees very well with the evidence of the aquatic Mollusca and points to perceptibly colder conditions in central California during Pliocene time, but makes it certain that this cold facies was due not to elevation, but to actual migration of isotherms. Such a condition could not have been a local phenomenon, but was probably widespread on the Pacific coast."

In western Europe, thanks especially to the persistent labor of Clement and Eleanor M. Reid, knowledge of the Pliocene flora is extensive and on an established observational basis. In England the Lower and Middle Pliocene are marine; hence are without plant deposits. The only beds yielding plants are known as the Cromerian, or Cromer Forest beds, of extreme Upper Pliocene age. Fortunately, older Pliocene beds have been discovered in Dutch Limburg and adjacent Prussia, and made known by the Reids[24] in a splendid monograph published in 1915. The oldest of

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[22] Oswald Heer: The Primæval World of Switzerland, vol. 2, 1876, p. 138.

[23] Harold Hannibal: Torr. Bot. Club Bull., vol. 38, 1911, pp. 329-342.

[24] Clement and Eleanor M. Reid: The Pliocene flora of the Dutch-Prussian border. The Hague, 1915.

these floras, known as the Reuverian stage or flora, is Middle Pliocene in age. It includes a flora, mainly of seeds and fruits, of nearly 300 species, of which some 230 have been determined with a considerable degree of certainty. This flora has very little relationship with the present flora of Europe, the Caucasus, or the Mediterranean, but clearly finds close affinity with the "living flora of the mountains of western China, and to its allied geographical provinces—Japan, the Himalaya, Eastern Tibet, and the Malay Peninsula."

The Reids conclude that the Reuverian assemblage was a temperate flora similar to that which belongs to the moist and temperate forest belt found only on the Chinese mountains. The late Miocene and early Pliocene flora was originally essentially circumpolar in distribution, but increasing cold forced it southward along at least three migration routes. One path was along the mountains of Atlantic North America, a second through eastern Asia, where both persist today, and which accounts, as Asa Gray long ago pointed out, for the striking resemblance between these two floras. The third route was through western Europe, as attested by the remains found in the Reuverian flora; but when increasing cold forced this farther south, it was crushed out against the east-west mountain ranges and disappeared.

A slightly younger flora, and one very distinct from the Reuverian flora, is the Upper Pliocene Teglian flora of Limburg. It includes about 133 forms, of a decidedly cool-temperate character, which bears a close resemblance to the European flora of the present day. That is, all the plants with Malayan and Australian affinity had disappeared, and although a few distinctive Chinese and Japanese species still remained, by Upper Pliocene time, as represented by the Cromerian from England, the European facies had been fully established, the peculiar Chinese element having disappeared, except for such species as still live in Europe.

Part II. Origin and Differentiation of geologic Climates

EARLY CLIMATES NON-ZONAL

We have now passed somewhat hastily in review the salient facts relating to geologic climates as interpreted by and through fossil floras. This has been supplemented and confirmed in many cases by an appeal to the pronouncement of fossil faunas. It is perhaps not too much to say that it has now been demonstrated beyond reasonable question that climatic zoning such as we have had since the beginning of the Pleistocene did not obtain in the geologic ages prior to the Pleistocene. I think this statement of conditions is very generally accepted by geologists and paleon-

tologists—in fact, I am at a loss to know how the data available can be otherwise interpreted.

Assuming, as we now seem justified in doing, that this cardinal fact has been established, the human mind is so constituted that it is not satisfied to stop at this point, but it must seek, if possible, an explanation of the cause or causes that gave rise to this marked difference between the pre-Pleistocene and subsequent climatic distribution. In other words, Why was there no climatic zoning in the age before the Pleistocene? There must be a reason, if we can but find it.

In seeking an answer to this question, I may confess that I have been led far afield—much farther, in fact, than I had originally intended to go. As present-day climatic differentiation is so dependent on atmospheric conditions and variations, there is no logical stop, in looking backward over the climatic conditions that have obtained in the successively older and older geologic ages, short of a consideration of the original atmosphere; and, having reached this point, logic urges a consideration of the earth on which it rested, perhaps including the origin of the earth itself. I hasten to add, however, that it is not my intention to venture a full discussion or analysis of these profound problems for two good and sufficient reasons, not the least of which is lack of time.

The zonal distribution of climate as we know it today results from the direct, though variously modified, control by the sun. If the earth was without an atmosphere and had a homogeneous surface throughout, the distribution of heat would be strictly by latitude, producing what has been called solar climate. But the problem is by no means so simple, for solar climate is modified and delimited by a number of important factors, such as the presence of an atmosphere containing water vapor, carbon dioxide and other gases in varying amounts, together with dust particles from various sources. Solar climate is also further modified to a marked extent by certain physical features of the earth itself, such as continents, plateaus, mountains, deserts, oceans, etcetera.

It appears to have been a pretty general assumption, especially in late years, that the sun exercised approximately the same control over earth atmosphere, surface temperature, or climate in past geologic ages as it is known to do at present. If this is true it would be impossible to escape the conviction that climates should have been disposed in zones throughout the whole of geologic history—that is to say, this result would have followed inevitably and of necessity if the sun had dominated earth atmosphere as it now does; but, if the biologic criteria of the past have been correctly interpreted, the sun did not so dominate. Or, to be on the safe side, we should perhaps say that the sun's dominancy has, at

most, not been continuous and uninterrupted, for on no other basis do certain observed facts seem explainable. For example, polar geniality of climate, such as occurred again and again in the ages before the Pleistocene, can not be explained on the basis of unmodified solar control. Glaciation such as that of the "Permo-Carboniferous," which occurred in and adjacent to the tropics, is impossible under a vertical or nearly vertical sun, or at least not without an elevation of the land-mass that is out of all proportion to the observed stratigraphic and structural data.

In other words, it seems evident that there must have been some other factor or factors that operated to obscure or modify solar control. Can these be predicated with any reasonable degree of certainty?

CONSIDERATION OF THE ATMOSPHERE

In seeking a possible answer we may first consider the atmosphere. It need hardly be recalled that the atmosphere, the outer gaseous envelope surrounding the earth, is a mechanical mixture of oxygen, nitrogen, a small increment of carbon dioxide, and still smaller quantities of various other gases, together with water vapor in amounts that vary with temperature, locality, and season. The height to which the atmosphere extends above the earth is not known, though it exceeds 100 miles, and one-half the air is below the 20,000-foot level. According to Humphreys,[25] "At an elevation that in middle latitude averages about 11 kilometers [36,000 feet] the temperature of the atmosphere becomes substantially constant, or, in general, ceases appreciably to decrease with increase of elevation; this is, therefore, the upper limit of distinct vertical convection and of cloud formation."

A beam of sunlight in passing from the earth to the sun has the rapidly vibrating light waves transformed in large part at the surface of the earth into slower vibrating heat waves. In passing from the outer limit of the atmosphere to the surface of the earth, the beam of sunlight is subject to certain losses of energy, such as absorption by the gases and vapors of the atmosphere, especially the water vapor bands, the "scattering of light toward the ground from the direct solar beam by the molecules and dust particles," and from the loss by scattering into space by these dust particles. Now as to the effect of the atmosphere itself: It is well known that the oxygen and nitrogen are transparent to both incoming light rays and outgoing heat rays, while the water vapor and carbon dioxide are largely opaque to the outgoing heat rays. This, then, is the crux of the whole matter. The water vapor in the atmosphere, aug-

[25] W. J. Humphreys: Volcanic dust as a factor in the production of climatic change. Washington Acad. Sci. Jour., vol. 3, 1913, p. 367.

mented by carbon dioxide, acts as a trap to imprison the heat rays, thus producing the so-called blanketing effect. Any increase or decrease in the efficiency of this thermal blanket may have very profound and far-reaching results.

POWER OF CLOUDS IN REFLECTING THE SUN'S RAYS

Some very recent observations (1918) were made by Dr. L. B. Aldrich,[26] of the Astrophysical Observatory, on the power of clouds to reflect the rays of the sun. By means of a captive balloon he was able to secure readings from a pyranometer from the surface of a fog bank when the upper and lower surface of the fog lay respectively about 2,800 feet and 1,000 feet above the ground. He says:

"The measurements were singularly concordant and satisfactory, and gave as the mean reflecting power of the fog during the interval from 7 until 11 o'clock 78 per cent. No apparent change owing to the change of the height of the sun during that time was observed. However, it is hardly questionable that if the measurements had been made nearer sunrise the reflective power of the fog would been found somewhat greater. Accordingly, we must suppose that if there should be a planet completely covered with smooth clouds it would reflect upwards of 78 per cent of the solar rays otherwise available to heat its surface. In the case of the earth, the cloudiness is about 50 per cent, so that if the clouds were as smooth on this surface as the clouds observed, the result would be that they would reflect away about 39 per cent of the solar rays and make ineffective to warm the earth. Taking this result in connection with the consideration of the other parts of the earth's surface, it appears that the reflecting power of the earth as a whole for solar rays of all wave lengths should be in the neighborhood of 43 per cent."

The value of these observations is not to be underestimated. If the earth was surrounded by a complete cloud envelope through which only approximately 20 per cent of the sun's rays could penetrate and become available for heating the earth's surface, it can hardly be questioned that this source of heat is inadequate.

SOURCES OF HEAT

In general.—According to the late S. P. Langley, the earth, on the average, is still over 52 per cent cloud-covered, and this condition, be it recalled, is with the sun as the direct controlling factor in heating the earth's surface. It was long ago suggested that this cloud envelope, or thermal blanket, was much more extensive in the ages before the Pleistocene than it is now; in fact, it is held that the cloud mantle was practically complete. Let us examine the data and see what warrant there is

[26] Smith. Misc. Collections, vol. 70, 1919, p. 28.

for any such conclusion. As pointed out several times before, it must have followed that if the sun had dominated earth atmosphere throughout measurable geologic time to the extent it now does, temperatures would have been distributed by latitude; hence the solution hinges on the correctness of the biologic interpretation of a non-zonal arrangement prior to the Pleistocene. If this has been shown from trustworthy evidence admitting of no other conclusion—as indeed I believe it has—then, as Abbot has stated in a recent letter to me, "one must follow with the conclusion that the earth's heat supply in those times did not come principally (as now) from a source subtending a small solid angle."

It now follows that several solutions may be suggested. These have been formulated by Abbot as follows:

"1. The sun was shut off by clouds and the heat came from within the earth.
"(*a*) Internal heat persisted.
"(*b*) Radio-active heat was available.
"2. The sun was effectively bigger.
"(*a*) Sun then an extensive nebula.
"(*b*) Sun's rays reflected by extensive nebula."

Heat from a bigger sun.—The second of these suggested solutions, namely, that which postulates an effectively larger sun, has had a number of advocates. For instance, it is given quite favorable consideration by Dr. Abbot in his well-known book on "The Sun," but he writes me that he does not now think so well of it as he formerly did.

The present sun is about 866,000 miles in diameter. It is giving up energy at a tremendous rate, which it is possible to measure with great accuracy. The manner in which the sun's heat is maintained is not certainly known, but the hypothesis that finds widest acceptance, that of Helmholtz, assumes it to be due to the gravitational infall of matter at its outer rim, by the transfer of motion into heat. It has been calculated that an infall of this kind of 250 feet per annum would be sufficient to maintain the present loss of energy. This, of course, implies that the sun must have had a definite beginning, just as it shows it to be tending toward an unmistakable end; in fact, Newcomb has calculated that at the present rate of loss of energy the sun, in seven million years, will be reduced to one-half its present size. Astronomers are not agreed as to the probable age of the sun, though, so far as I can learn, few of them incline to regard it as more than one hundred million years old, and many have hesitated to concede more than fifty million years to its existence. This is totally at variance with the demands recently made as to the age of the earth, for it is impossible to conceive of the earth as

existing without the sun. Thus Barrell, in his most recent estimates, places the age of the earth at a minimum of seven hundred and fifty million years, with the possibility that it may be as much as one billion five hundred million years! Certainly there must be some readjustments or mutual concessions between astronomers and geologists before these widely discordant figures can be brought into harmony!

It is not only possible, but perhaps reasonable, to postulate a much larger, more diffuse sun during the earlier stages of its existence, perhaps a sun so large as to fill the orbit of the earth. With such a large-angle sun the rays would fall nearly vertical on perhaps a whole hemisphere at once. This would offer an explanation for an equable, non-zonal distribution of climate and would make possible the growth of tropical or subtropical vegetation within the polar circles. It would also provide an explanation for tropical or subtropical glaciation, given a sufficient elevation of the land-mass.

But it appears that there are certain astronomical objections that stand in the way of accepting this in its entirety. Just what they are I can not say, but I am informed by Dr. Abbot that he and Professor Moulton, of Chicago, went over the subject some years ago and reached the conclusion that "not more than double the life of the sun as a source of radiation capable of holding up the earth temperature could come that way under the most favorable assumptions."

Heat from the earth itself.—We may now turn to the other assumption, namely, a heat supply from the earth itself. The suggestion that the sun was shut off by clouds and the heat came from within the earth itself is, of course, not new; in fact, it follows as a natural corollary to one of the most prominent of the theories advanced to account for the origin of the earth. It is the essential basis of the views advocated by Dr. Marsden Manson in his paper on the "Evolution of climates" and in numerous subsequent publications, though it may be added that it does not depend on the acceptance of the nebular hypothesis of earth origin.

Setting aside for the moment the discussion of primitive earth temperatures, we may consider the action that may reasonably be presumed to result under this hypothesis of a dual heat supply. Granted an initial surface temperature, from whatever source derived, that was higher than that now existing, it can not be doubted that a larger percentage of the water now existing in the seas, lakes, and rivers must then have existed in the form of vapor. As it ascended, this vapor would be condensed into clouds, forming a spheroidal cloud envelope surrounding the earth. It also seems certain that under this hypothesis the sun must have exerted

substantially the same zonal action on the outside of this cloud spheroid that it now does upon the present cloud surface and, within the limits of certain modifying factors, upon the earth's surface. To quote from Hilgard,[27] who has written in strong advocacy of this hypothesis:

"The tropical belt with its strong ascending currents, low barometer, and high temperatures; two adjoining arid belts with descending currents and high barometer, and the temperature zones to poleward, with variable but generally low barometer, would be defined on the cloud spheroid as they now are on the earth's surface, but with greater regularity, though perhaps less sharply defined."

A certain amount of earth heat, carried up by convection currents, is lost by radiation into space, but the solar radiation falling on the outside of the cloud spheroid would in part compensate for this loss, and thus the sun would actually become a conservator of earth heat without directly influencing the temperature of the earth's surface. This great amount of moisture in the atmosphere naturally led to greater and more rapid precipitation, and the rainfall was undoubtedly greater than at present.

The further elaboration of Manson's hypothesis has been so graphically and succinctly stated by Hilgard that I venture to quote from his paper. He says:

"The isothermal spheroids or shells corresponding to our present temperatures would at first be at heights more considerable than at present; but as the heat carried up from the earth's surface was more and more lost by radiation into space from the exterior cloud-surface, the isothermal shells would gradually descend, and the temperature of the falling rains would become lower, so as under favorable conditions to fall as snow. It is clear that snowfall might occur at any period of the earth's evolution on high mountain ranges or plateaus, and there the accumulations of snow might at any period have formed nevees and glaciers with their well-known effects. . . . Owing to the higher radiating power of the earth-surface as compared with the ocean, as well as its much lower specific heat, the earth must have cooled more rapidly than the oceans by radiation alone. In addition to this, the water flowing from it into the seas would carry off a large amount of heat. Even while the ocean still received heat from its bed, the land areas would be a cooling agency especially for the ocean depths, while the warm oceanic surface waters would be supplying abundant vapor for precipitation on the relatively cooler land areas. The latter would finally fall to so low a temperature as to receive their precipitation in the form of snow, thus inaugurating the glacial period, during which the isothermal shell of, say, the freezing point of water, and below, descended near to the earth's surface. As the ocean also gradually cooled and evaporation diminished, the protecting cloud-envelope became thinner, first in the tropics and its flanking belts of lesser rainfall (which

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[27] E. W. Hilgard.

later became the arid belts) ; and thus gradually the zonal solar regime was established."

These are the essential features of Manson's theory and, whatever its fate may be, I thoroughly agree with Hilgard that it must be given very serious consideration. Of course, objection has been raised against the acceptance of this hypothesis of a higher initial and subsequent diminution of surface temperatures. We are told, for instance, that, owing to the law of conductivity of the rocks, the transmission of earth heat to the surface must have ceased as a practical factor very soon after the formation of an earth crust. We know, or think we know, that there is ample heat in the earth's interior, for if the ratio holds good of an increase of one degree for about 60 feet of depth, we shall have the stupendous temperature of 348,000° F. at the center. But conduction is not the only means by which earth heat may be brought to the surface. Faults, fractures, denudation, thermal waters, orogenesis, and, of course, vulcanism are continually liberating appreciable amounts of heat. On the basis of vulcanism—if this is a really competent criterion—the earth appears to have been cooling since earlier geologic time; for, though by no means extinguished, vulcanic activity is much less evident now than it has obviously been in the past.

Radioactive heat.—But, fortunately or otherwise, we are not dependent for a possible solution of this problem on an original earth heat, whether developed from a cooling nebula or by impact and pressure of separate solid increments. The recent wonderful discovery of radioactivity introduces a wholly new and unsuspected set of factors; but the facts are so newly available that the possibilities and limitations are not yet fully worked out. It is now known that uranium and thorium, elements having the highest atomic weights known, are the parents of a series of radioactive elements. Each of these elements breaks down into a descendant series by giving off positively charged atoms of helium at an enormous velocity, by negatively charged electrons, also with high velocity, and by certain rays of the nature of Röntgen or X-rays. After a very long but measurable length of time a stable element is the result, as, for instance, lead, which results from the breaking down of uranium. This process is necessarily accompanied by the evolution of heat; in fact, as Barrell [28] has said:

"It has been found that radioactivity gives such an embarrassingly large quantity of heat that it has been necessary to assume the restriction of uranium and thorium with their observed percentages to the outer 40 miles

[28] Joseph Barrell: Rhythms and measurements of geologic time. Bull. Geol. Soc. Am., vol. 28, 1917, p. 839.

of the earth's crust, since otherwise the earth would be heating up with geological rapidity, instead of being a body slowly cooling or in thermal equilibrium."

It is not known to what depth in the earth the various radioactive minerals extend, nor is it known what effect great pressure may have on radio emanations; but inasmuch as these elements have the highest atomic weights known, it would seem a fair presumption that there is a progressively greater condensation of them toward the center. In any event, it is obvious that the restriction of these radioactive elements to the outer 40 miles of the earth's crust is a mere convention, devised for the sole purpose of getting around what might otherwise be an awkward condition of being obliged to account for too much heat. It would seem to me that it is within the bounds of possibility that this may be the key to an explanation of an augmented earth heat during the earlier geologic ages. As it seems now to have been demonstrated with more than a reasonable degree of certainty that the breaking down of the radioactive elements into a descendant series, with the consequent evolution of heat, is a process that requires a measurable, albeit a very long, period of time, it may be that this is the explanation of a higher earth heat during the earlier ages, and that it reached its maximum long prior to the Pleistocene, since which time it has been declining. This offers an explanation of the present cooling globe or one in approximate thermal equilibrium. But this is pure speculation, as difficult to prove as to disprove. However, in the next paragraphs certain facts will be set forth that seem to call for a higher inherent earth heat than we have had since the beginning of the Pleistocene.

OCEAN TEMPERATURES

A word may be said at this point in regard to the temperature of the ocean waters during early geologic time. It now seems to be settled beyond serious question that the waters of the early oceans were warm—in fact, that they were not permanently cooled as they are now until the approach of Pleistocene time. This does not necessarily mean that there may not have been some fluctuation in their temperature from time to time, for there doubtless was; but, taken by and large, the oceans were warm from the equator to the poles. On this point Ulrich [29] says:

"Taking the geological marine record, as preserved in the fossiliferous rocks from the Cambrian to the Tertiary, it suggests equable, mild, almost subtropical climates over the whole Northern Hemisphere in all the ages represented."

[29] E. O. Ulrich: Revision of the Paleozoic systems. Bull. Geol. Soc. Am., vol. 22, 1911, p. 352.

Ulrich also adds that there is undoubted evidence, notably in the early Cambrian and early in the Pennsylvanian, when "frigid conditions occurred at least locally." This is the very crux of the matter, for it seems clear that while there are undoubted evidences of glaciation, they were, at least for the most part, so very local in their effect that they seem to have made little impress on the temperature of the oceans, and hence on the continuity and distribution of marine life. As bearing on this point, Dr. John M. Clarke has expressed his opinion as follows:

> "There is of course plenty of evidence of cold weather periods and also of local cold throughout Paleozoic history. I can not say that such determinations are, in any single particular within my knowledge, dependent upon the fossils of the rocks; nor can I say that the obvious evidences of recurrent land glaciation are connected in any way with or supported by any facts producible from coexistent faunas or floras. I have worked out with some particularity a somewhat circumscribed glaciation in the later stages of Devonian time. That it has had any effect on the marine faunas I can not say; whether it has affected the estuarine or river faunas represented by the Devonian fishes, we can not tell because we are not able to deduce from their data the adaptations of those creatures."

The present average temperature of the surface of the oceans varies from about —1.7° C. at the poles to about 27.88° C. in the warmest (Indian) ocean. The average surface temperature of the oceans as a whole is as follows: Atlantic, 16.9° C.; Pacific, 19.1° C.; Indian, 17° C.

It is, of course, well known that water is a very poor heat conductor. According to Grabau, it has been calculated

> "that a mass of water 5,000 meters deep, and of a uniform temperature of 0° C., would, if in contact with a heat source of 30° C. at the surface, experience the following rate of warming, providing no other factor, such as convection currents, etc., entered in. In 100 years no appreciable increase in temperature would be found at a depth of 100 meters; in 1,000 years not one per cent of the surface warmth is to be found at a depth of 300 meters, while it takes 10,000 years to carry this fraction of the surface warmth to a depth of 1,000 meters, and 1,000,000 years to carry it to a depth of 4,900 meters. After 1,000 years the temperature at a depth of 100 meters will be 7.3° C., while at 200 meters it will be only 0.6° C."

In actual practice, however, the warming of a body of water is more rapid, due to the absorption of the sun's rays, vertical convection currents, and the sinking of heated saline waters whose density has been increased by the surface evaporation; but at best the process is a slow one. If, as has now been demonstrated, the process of heating up a great body of water is such a slow one, it must follow that it will give up its heat with an approximate degree of slowness. Now, the very pertinent

question presents itself: What was the source or sources of heat that kept the oceans of the globe so continuously warm during all or most of early geologic time? According to H. F. Reid,[30] the earth's surface at the present time receives from the sun at least 2,000 times as much heat as from the interior of the earth itself; yet, covering the period including the Pleistocene and subsequent time, during which at least the sun is admitted by all to have dominated earth temperatures, the heat supplied from this source has not been sufficient to remove the polar ice-caps or raise the surface temperature of polar waters even to 0° C., though it is to be acknowledged that in many areas—perhaps everywhere—the remaining ice-covering is being very slowly reduced.

In seeking a solution of this problem of source of supply of heat, let us assume for the moment that it came from the sun and see what reasonable conclusions can be reached on this basis. In the first place, the whole matter is seemingly thrown out of court, as many times pointed out in this paper, on the ground that if the sun had been the principal source of heat in pre-Pleistocene time, terrestrial temperatures would of necessity have been disposed in zones, whereas the whole trend of this paper has been the presentation of proof that these temperatures were distinctly non-zonal. Therefore it seems to follow that the sun—at least the present small-angle sun—could not have been the sole or even the principal source of heat that warmed the early oceans.

Assuming again, for the sake of argument, that the conclusion regarding the non-zonal disposition of temperatures was in error, and that the heat for warming the early oceans actually did come from the sun, then it must have been from a hotter, small-angle sun or from a diffuse, large-angle sun. In either case the first effect would be an increase in surface temperatures, which would increase evaporation and thus make the cloud envelope more complete and efficient; and this in turn would automatically, though perhaps intermittently, shut off the sun's rays from access to the earth's surface. Considering the extreme slowness of the absorption of heat by water and the great amount that must have been necessary to heat up and maintain the warmth of the oceans, it becomes increasingly difficult—not to say impossible—to believe that it could have been supplied by the sun under the conditions predicated.

EVIDENCES OF GLACIATION

By many it is thought that one of the strongest arguments against a gradually cooling globe and a humid, non-zonally disposed climate in the ages before the Pleistocene is the discovery of evidences of glacial action

[30] Science, new ser., vol. 29, 1909, p. 29.

practically throughout the entire geologic column. Hardly less than a dozen of these are now known, ranging in age from Huronian to Eocene. It seems to be a very general assumption by those who hold this view that these evidences of glacial activities are to be classed as ice ages, largely comparable in effect and extent to the Pleistocene refrigeration, but as a matter of fact only three are apparently of a magnitude to warrant such designation. These are the Huronian glaciation, that of the "Permo-Carboniferous," and that of the Pleistocene. The others, so far as available data go, appear to be explainable as more or less local manifestations that had no widespread effect on, for instance, ocean temperatures, distribution of life, etcetera. They might well have been of the type of ordinary mountain glaciers, due entirely to local elevation and precipitation, of which we have many examples now existing. And in this connection it may not be out of place to call attention to the difficulty of accurately fixing in the time scale these often widely scattered areas exhibiting glacial phenomena. It seems to me not only possible, but entirely probable, that there is a considerable element of error in the determination of the stratigraphic position and assumed or implied synchroneity of certain of these ancient glaciated areas. They are often unaccompanied by fossil remains, and hence their position can only be fixed within very broad limits.

PHYSIOLOGICAL ACTION OF INCREASED CLOUDINESS ON PLANT LIFE

As already abundantly set forth in preceding pages, the conclusion seems inevitable, if the data has been correctly interpreted, that there was increased cloud production during the early geologic ages which shut out access of the sun to the earth's surface. As the question is almost certain to be raised as to the probable physiological effect of this cloud mantle on plant life, I have taken occasion to ascertain recent observations and opinion on this point. Inasmuch as a very considerable percentage of existing plants grow under conditions where they seem to demand, or at least tolerate, strong sunlight, it has seemed to many a fair inference that similar condition must have applied to the earlier floras—that is to say, that their presence is proof positive of the presence of full sunshine—but the facts now available do not bear out this contention.

In this connection I consulted with Dr. John M. Coulter, of the University of Chicago, and through him with Dr. William Crocker, of the same institution. Among other things, Dr. Crocker states:

"Late work is indicating very strongly that the main effect that light has on the development of the plant is its effect on photosynthesis and through

the food thus manufactured on the rate and course of development of the plant."

Dr. Crocker also directed my attention to an important paper by Messrs. Brown and Escombe,[31] in which they record results of the effect of varying amounts of light on photosynthesis. This work was carried on at Kew, England, where so-called full sunlight is not very full, owing to prevalent cloudiness. They say:

"When a leaf is exposed to full sunshine the radiant energy which is utilized for the photosynthetic process represents only a very small part of the total incident radiation. If we restrict the term "economic coefficient" to the ratio of these two values, the full radiation falling on the leaf being taken as 100, it is evident that the leaf is an extremely wasteful transformer of energy, since it receives a very large amount of superfluous energy which does not contribute to the main function of the leaf. That the photosynthetic rays, even in sunlight of very moderate intensity, are in excess of the power of the leaf to utilize them has been shown by the experiments described in Part 2, XXXX. It was found, for instance, where solar radiation of an average intensity of about 0.5 calorie per square centimeter per minute was reduced to about one-third of this intensity by passing through a thin canvas screen, forming an artificial 'cloud,' that it still contained an excess of photosynthetic rays over and above what was necessary to produce maximal assimilation in ordinary air; for by means of the revolving-sector method the intensity of the radiation could be still further reduced to one-quarter—that is to say, to one-twelfth of the original amount—before there was any sensible diminution of the assimilatory power of a leaf submitted to its influence."

It remains to ascertain the amount of light that would be available for photosynthetic processes under conditions of a complete and permanently overcast sky. These data are supplied in a paper recently published by Dr. H. H. Kimball,[32] of the U. S. Weather Bureau. He says:

"Photometric measurements made at Mount Weather, Virginia, show that with a clear sky the total illumination on a horizontal surface varied from 10,000 foot-candles in June to 3,600 foot-candles in January. . . . The illumination on a horizontal surface from a completely overcast sky may be half as great as the total illumination with a clear sky, and is frequently one-third as great. On the other hand, during severe thunder-storms at noon in mid summer, the illumination may be reduced to less than one per cent of the illumination with a clear sky."

These results indicate that the supply of light would undoubtedly be ample for plant needs, even with a complete cloud mantle. Although

[31] H. T. Brown and F. Escombe: Researches on some of the physiological processes of green leaves, with special reference to the interchange of energy between the leaf and its surroundings. Proc. Roy. Soc. London, Series B, vol. 76, 1905, p. 86.

[32] H. H. Kimball: Photometric measurements of daylight illumination on a horizontal surface at Mount Weather, Va. Monthly Weather Review, vol. 42, 1904, p. 652.

plants now seem to tolerate strong sunlight, it is possible, even probable, that through exposure to strong light they have come to be greater light-demanders. The ones grown under the postulated cloud conditions of the earlier geologic ages may have corresponded more nearly to our present shade-tolerant forms.

In the living flora the ferns hold a subordinate position, though there are perhaps as many specific types now as there were at any time in the past. The living ferns are preeminently shade-loving plants; in fact, few of them can long survive exposure to strong sunlight. Is it not possible that their shade-loving habit is a direct inheritance from the early geologic ages, when they were developed under a practically continuous cloud mantle? Ferns have now essentially the same structure, method of reproduction, and ecological requirements that they had throughout the Paleozoic and Mesozoic. If the ferns of the earlier ages were developed under conditions of strong sunlight, they have completely changed their habit without this fact being reflected in the structure.

OBSTACLES TO THE ACCEPTANCE OF EARTH HEAT

Other supposedly serious obstacles to the acceptance of this hypothesis have recently been formulated by Barrell.[33] He holds that "the amount of radioactivity known to exist in the crust appears to be adequate, or more than adequate, to account for the whole emanation of heat," but his deduction from this, namely, that "there is no evidence, therefore, that the earth is cooling and that the crust gave forth more heat in earlier times," does not seem clear. Under the present system of solar control, there may be a compensatory adjustment of heat derived from the two sources (earth and sun) that was lacking when the sun was not the dominant factor it now is. To my mind, logic supports the contention of a cooling globe during the major part of geologic history.

Barrell's second point—namely, that the deeper parts of many pre-Cambrian formations, such as the Unkar and Chuar, exposed in the depths of the Grand Canyon section, do not show regional metamorphism, and hence that the "temperature gradient since the late pre-Cambrian could not, therefore, have been notably higher than at present"—appears to be based on the supposition that the entire section of perhaps 20,000 feet was buried and remained at a great depth for ages, while as a matter of fact it probably came to the surface in late Algonkian time and remained at or near the surface for a very long time, as shown by the

[33] Joseph Barrell: Rhythms and the measurement of geologic time. Bull. Geol. Soc. Am., vol. 28, 1917, pp. 901, 902.

fact that there is very little Cambrian, no Ordovician, Silurian, or Devonian, and comparatively little Pennsylvanian in this section.

While the above may be a satisfactory explanation of the specific case cited, it may not explain lack of regional metamorphism in general. This point is touched on by Manson [34] in his recently published paper, his statement reading as follows:

"The conductivity of the crust of the earth is so low that the heat which could be made available as a climatic factor through this process [liberation of earth heat] is negligible, except for very short periods over very limited areas. This extremely low conductivity was one of the highly conservative factors imposing the long duration of this source and its liberation is recorded in the altered and unaltered sedimentations and severe crustal ruptures up to the present era."

This interpretation means that earth heat, given off very slowly owing to the low conductivity of the rock crust, was stored in warm oceans. The warm waters increased evaporation and cloud formation, thus conserving the heat, which process was also aided by the sun's rays falling on the outside of the more perfect cloud spheroid. This slow transmission of heat through the rock crust has not only acted as a conservator of earth heat, but explains why rocks brought from great depths show so little evidence of having been subjected to great heat.

His third contention is that the "quantity of heat which the earth delivers to the atmosphere is now, and must always have been, inconsequential in comparison with that derived at present from the sun"; hence, for example, "to have conducted five times the heat, the temperature gradient would have to be five times as steep, giving a temperature of molten rocks at a depth of five miles."

This ignores wholly the value of radioactivity, and in another part of the same paper (p. 839) Barrell says: "The discovery of radioactivity cuts out all solid basis for calculating age [of the earth] from the flow of solar energy or the temperature gradient of the earth." No further comment on this point seems necessary.

Barrell's fourth proposition is as follows:

"The presence of banding in certain argellites of early pre-Cambrian times in Norway and Canada, associated with ancient glacial deposits, is directly comparable with the annual banding in stratification in Pleistocene clays in those same regions, and testifies to the dependence of temperature in those times on solar radiation with an atmospheric condition which permitted the existence of winter."

[34] Marsden Manson: Geologic and present climates, 1919, p. 217.

I submitted this statement to Dr. W. C. Alden, who writes me as follows:

> "It seems like a far cry from banded pre-Cambrian argillites to solar radiation and seasonal temperatures, yet there may be a direct and logical relation. The reasoning may be correct, but I would hesitate to jump directly to the conclusion stated. There seems to be no doubt that variation in stream-flow due to variation in precipitation resulting from seasonal changes will produce lamination in fine sediments, but I doubt if all lamination is produced in this way. Any other recurring condition that affected precipitation (rainfall) and the load of sediment carried by the streams might produce such lamination. The factor of recurrence at more or less regular intervals, however, strongly suggests seasonal recurrence. This might be without the occurrence of *winter*, meaning by winter a cold season such as we experience in the temperate zone and higher latitudes. . . . I am not sure the lamination of sediments associated with glacial deposits might not be produced under other conditions. It requires close analysis to eliminate alternative possibilities when one is considering what might have happened in pre-Cambrian times."

Dr. R. S. Bassler, with whom I have discussed this question, has expressed the opinion that the banding in the pre-Cambrian argillites may possibly be due to segregation from shales more or less homogeneous when originally deposited. As examples he cites the many banded shales—all unaccompanied by evidences of glaciation—in Ordovician, Silurian, and Devonian rocks. Dr. E. O. Ulrich, with whom I have also discussed the problem, doubts the efficiency of the segregation hypothesis and considers the banding as purely a question of sedimentation. He is of the opinion that there are so many factors influencing the deposition of fine sediments that it is unwise or unsafe to pin much faith to variation in stream-flow and consequent deposition as dependent on seasonal changes, especially at a time so remote as the early pre-Cambrian.

In view of these conflicting opinions, it does not seem that this contention can be considered as much more than a possibility. It will have to be supported by more exact information before it can be accepted.

Barrell's fifth objection reads as follows:

> "The abundance of carbon in the clays of early pre-Cambrian time suggests the presence of sunlight sufficient to carry forward photosynthesis in plants and therefore the absence of an extremely dense cloud envelope."

This is a generalization on a very insufficient and insecure basis; for while pure carbon or graphite may be produced by the metamorphosis of coal or other vegetable debris, it by no means follows that it was always so produced, especially in the older rocks. Carbon is formed in meteorites in a purely inorganic manner, as by the decomposition of metallic

carbides. Moreover, the carbon or graphite in the Laurentian rocks is so vast in quantity—more, Sir William Logan once said, than in any similar area of Carboniferous rocks in the world—that it would require for its production an incalculable mass of algæ, which were without woody substance, and hence low in carbonaceous matter. And, further, many plants, notably red and brown algæ, do not require sunlight for their assimilation processes; hence, if we should grant that the pre-Cambrian carbon had been reduced by plant life, it would by no means follow that this life process implied sunlight. It could have gone forward in absence of direct sunlight.

The last point Professor Barrell seeks to make is based on the fact that glacial conditions and, as he holds, periods of widespread aridity have recurred at intervals since Middle pre-Cambrian time; hence he concludes that the composition of the atmosphere and ranges of temperature have been subject to fluctuation through all geologic time.

The deductions based on glacial conditions apparently are on the supposition that all observed glacial activities are veritable ice ages having a profound effect on temperatures, life distribution, etcetera. The fallacy involved in this conception has already been set forth.

The criteria on which widespread aridity are predicated are not stated, though presumably based on the conventional doctrine of red beds, deposits of salt, etcetera. The great deposits of salt are presumed to have resulted from the evaporation of impounded saline waters. But has any one attempted to visualize the physical setting essential for the formation of a 100-400-foot bed of salt by evaporation? Is it certain that such deposits are proof positive of aridity?

The physical character of sediments and the interpretation of their mode of deposition has been used to prove aridity, but when—as, for example, in the case of the Old Red sandstone—interpretations of the same data range all the way from the permanent deserts postulated by Walther and Goodchild and the semi-aridity advocated by Barrell and Jukes-Brown to the contention of a marine origin by Hugh Miller and recently confirmed by Macnair and Reid, the layman may well hesitate.

There is undoubtedly an element of truth in all of these several contentions, but it is when they are forced to bear too great a burden that they falter. As Barrell[35] has well said in another connection:

> "In general, traditional criteria are liable to lead into error because they become accepted as axioms and are applied without further thought. They lag behind the development of a science."

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[35] Joseph Barrell: Dominantly fluviatile origin under seasonal rainfall of the Old Red sandstone. Bull. Geol. Soc. Am., vol. 27, 1916, p. 354.

REVIEW OF HYPOTHESES PROPOSED TO ACCOUNT FOR THE INITIATION OF GLACIAL ACTIVITIES

In general.—The broader problems that we have been considering naturally include the several hypotheses that have been advanced from time to time to account for the origin of glaciation. Most of these hypotheses were proposed to account for the initiation of the great Pleistocene ice age; but, as the evidence gradually accumulated and it became evident that there had been numerous other refrigerations, the burden forced on these hypotheses of explaining all glaciations became too heavy, and one after another they appear to have failed of adequacy. I have ventured to review several of the more prominent of these proposals and to point out where and why they seem to fail.

Shifting the position of the poles.—In order to account for the presence of tropical vegetation within the polar circles and of glaciation in middle latitudes, it was perhaps natural and seemingly logical to postulate a wandering of the earth's axis of rotation within its body—a shifting of the poles. This hypothesis was advanced nearly a century ago, and for a time found many advocates among geologists, and more especially among biologists, to whom it furnished an easy explanation of certain puzzling facts of distribution among plants and animals. They failed to appreciate, or indeed to perceive, that this shifting of the earth's axis is "really a problem of mathematics, as much as are the movements of precession and orbital perturbations." Hence astronomers and mathematicians have in general been opposed to hypotheses of polar migration, and Lord Kelvin, and more especially George H. Darwin, have apparently set the matter definitely at rest. Beyond a very slight possible movement, involving at the outside not more than 10 degrees, that may have taken place in the geographic position which the axis held at the consolidation of the earth, they conclude that polar migration is mechanically impossible.

Barrell has recently published an elucidating review of the "Status of hypotheses of polar wanderings," [36] which he concludes as follows:

> "It would appear that the assumption of polar wandering as a cause of climatic change and organic migrations is as gratuitous as an assumption of a changing earth orbit in defiance of the laws of celestial mechanics. Unless some wholly unsuspected forces are at work within the centrosphere, polar wandering has no more basis in science than Symmes's imaginings of a hollow earth. From all that is known at present the doctrine must be regarded as a vagrant speculation, not a working hypothesis."

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[36] Joseph Barrell: Science, n. s., vol. 40, Sept. 4, 1914, pp. 333-340.

Continental elevation hypothesis.—It is probable that, all things considered, there is a wider acceptance among geologists and others of the postulate that changes in temperature due to continental elevation are sufficient to account for the inauguration and control of glaciation than any other of the many hypotheses that are up for discussion. As Gregory says, it is attractive from its simplicity. It is of course well established that there was a measure of continental elevation and subsequent depression during, for instance, the Pleistocene invasion. This is proved by the prolongation of fjords and land valleys on the adjoining ocean floor, by the finding of littoral shells in submerged areas, and of marine organisms on lands now elevated, though in some cases the last-mentioned occurrence may have resulted from an ice-mass that filled and plowed out a shallow sea basin, thus pushing them onto and over the adjacent land. But whether the hypothesis of continental elevation is fully competent to account for the origin and control of glaciation at all times and in all places, and under the usual postulate of a solar control similar to that now obtaining, is much to be doubted.

In discussing the several advances and retreats of the Pleistocene ice-sheets, Ulrich[37] says:

> "Assuming that elevation is competent to bring about glacial conditions in areas of abundant precipitation, it seems to me that the subsequent melting and retreat of the ice-cap may be due chiefly to the subsidence of the areas, and that the subsidence resulted from overloading. In other words, that the isostatic equilibrium had been disturbed by loading, and that subsidence set in when the ice attained a certain limit of thickness. . . . Reaching the level of melting, the ice-cap was gradually removed, only to be rebuilt when the direction of movement was first stopped and then reversed."

Coleman,[38] in considering this problem of Pleistocene elevation, reaches a quite different conclusion. He says:

> "Local elevations of thousands of feet can hardly be conceived as taking place at the same time over most of North America, the whole length of the Andes and Patagonia, all northern Europe, the Alps, the mountains of Turkestan, the Himalayas and Altai Mountains, the Atlas region, Rewenzori, Kenai, and Kilimanjaro, the New Zealand Alps, and Kosciusko in Australia, not to mention other localities glaciated in Pleistocene times. The theory breaks down of its own weight."

Coleman also adds that in some cases elevation is actually hostile to the formation of ice-sheets, as witness the observations of Scott, that on the

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[37] E. O. Ulrich: Revision of the Paleozoic systems. Bull. Geol. Soc. Am., vol. 22, 1911, p. 353.

[38] A. P. Coleman: Glacial periods and their bearing on geological theories. Bull. Geol Soc. Am., vol. 19, 1908, p. 363.

Antarctic table-land, 9,000 feet above sealevel, the ice is dwindling and the glaciers retreating. In this area, at least, depression might extend glaciation by increasing precipitation.

If it were worth while, an indefinite number of quotations both for and against this elevation hypothesis could be made; but out of this wealth of more or less conflicting testimony, it seems to me there must come the conviction that it may nevertheless have played a relatively important, though not always the major, rôle in the production of glaciation. We know that even under the present system of solar control of temperatures, if there is given the requisite elevation and adequate precipitation, accumulation of snow and ice will result. It might even be possible on this basis to explain a majority of the evidences of glaciation that have been described from the earlier rocks; for, as already mentioned, they are or may be of the well known mountain type of glaciation. But it seems to me improbable, not to say impossible, with the atmosphere controlled by the sun, for elevation alone to account for the inauguration of the three major periods of glacial activity. The Pleistocene glaciation was most extensive in North America. It was laid down over a broad, fairly level plain, and to my mind there is no convincing evidence of a continental elevation that seems adequate to account for its initiation. Still less does it seem competent to account for the "Permo-Carboniferous" glaciation. As has been shown, however, even a moderate elevation coupled with non-solar control seems fully competent to explain all types of glaciation.

Changes in atmospheric circulation hypothesis.—This explanation, which was especially advocated by Harmer[39] as applied to the Pleistocene climate of northwestern Europe, is conditioned on changes in atmospheric circulation resulting from geographic changes such as variation in continental outline and elevation. It is, of course, well known that quite marked meteorological phenomena are dependent on or influenced by terrestrial configuration, but this hypothesis fails utterly to explain the initiation of the equatorial "Permo-Carboniferous" glaciation, or of tropical or semitropical temperatures in polar lands. Moreover, atmospheric circulation, as here made use of, is of necessity based on the assumption, not considered tenable by the writer, that the sun has controlled earth atmosphere throughout the whole of geologic time as it does now. That this was a minor contributing factor during Pleistocene and subsequent time is possible, but it could hardly have been more than this when we reach the points at which the glaciation took place—some on mountains,

[39] F. W. Harmer: Jour. Geol. Soc., vol. 57, 1898, pp. 405-472.

others on broad, low plains; some on small oceânic islands, others along seacoasts or on isolated mountains in the middle of a great continent.

Hypothesis of the variation in the atmospheric content of carbon-dioxide.—The general proposition that a change in the amount of carbon-dioxide in the atmosphere might be sufficient to initiate glaciation was suggested by Tyndall more than half a century ago, and in recent years it has received able advocacy by Arrhenius and by Professor Chamberlin. The present normal content of the atmosphere is about .03 per cent. According to calculations by Arrhenius, an increase of carbon-dioxide to .09 per cent would be sufficient to raise the temperature in the polar regions by from 12° to 16° F., giving a temperate climate, while a decrease by about one-half of the present amount would be sufficient to bring about a period of glaciation similar to that of the Pleistocene.

The slight changes required are so very modest in amount that it must be confessed this constitutes a very attractive hypothesis, especially after one has followed Professor Chamberlin's exposition; but when it is critically examined a number of objections obtrude that seem to remove it from the category of major factors in the initiation of glaciation or deglaciation. What seems to me to be a most formidable objection is the rapid and repeated fluctuations of the carbon-dioxide content of the atmosphere that must be postulated to account for the retreat and re-advance of glacial activity during the Pleistocene ice age, to say nothing of those of other geologic times. "Surely," as Edgeworth David [40] has said, "there is hardly scope here for a world-wide variation of carbon-dioxide in the earth's atmosphere repeating itself so frequently over such short intervals of time." That is to say, that why there should have been this intermittent activity, separated by millions of years in the earlier ages, and the sudden fluctuations in the Pleistocene, separated at most by a few thousands of years, is not apparent; also, it should not be forgotten that according to Schloesing,[41] and supported by Dittmar, the ocean exercises a powerful and potent control over the amount of carbon-dioxide in the atmosphere. The manner of this action and reaction is set forth by Gregory [42] as follows:

> "If the amount of carbonic acid in the atmosphere is diminished, the bicarbonatês in the sea are dissociated; the gas thus liberated is thus poured into the air, until the former equilibrium between the tension of the carbonic acid

[40] T. W. Edgeworth David: Conditions of climate at different geological epochs. Cong. géol. internat., Compt. rend., Tenth Session, 1906 [1907], p. 477.

[41] —— Schloesing: Sur le Constance de la Proportion d'acide carbonique dans l'air. Compt. Rend., vol. 90, 1880, p. 140.

[42] J. W. Gregory: Climatic variations, their extent and causes. Cong. géol. internat., Compt. rend., Tenth Session, 1906 [1907], p. 419.

in the atmosphere and in the sea is reestablished. Hence a reduction of carbonic acid in the air is automatically followed by the discharge of nearly as large a quantity from the sea, so that any reduction is distributed between the air and the ocean. Any increase of carbonic acid in the atmosphere is followed by a reverse change, and only one-sixth of the amount poured into the atmosphere is retained there. It is true that great variations in the relative extent of sea and land would affect the dissociation pressure of the bicarbonates in the sea; but it would require a great reduction in the area of the sea surface to affect the equilibrium appreciably."

Again, it is to be pointed out that there is a non-coincidence of dates for periods of glacial activities. In accordance with the well-known law of diffusion of gases, any variation of the carbon-dioxide content of the atmosphere should affect the temperature of the whole world simultaneously, although, as shown by Arrhenius, it need not be the same in all latitudes; but it might be expected that corresponding latitudes in the hemispheres would exhibit practically the same effects. But the facts of historical geology do not altogether substantiate this supposition. Another weighty objection is offered by the fact that certain conditions that might have been expected to influence the variation of carbon-dioxide in the atmosphere have not been followed by the glacial activity the theory would call for. For instance, those periods of active consumption of carbon-dioxide, as marked by the formation of great limestone deposits, must have been supplied from the atmosphere. Among the greatest limestone-producing periods are the Mississippian, Jurassic, Cretaceous, and Eocene; yet none of these was followed by glacial manifestations. The Miocene and Pliocene, which *were* followed by pronounced glaciation, have far less of known limestone or coal accumulation than the Pennsylvanian or Cretaceous, both of which are without glacial activities.

Periods of intensive vulcanism, such as occurred in the Devonian, the Permian, the Upper Cretaceous, the Eocene, and the Oligocene, were not followed by marked glacial activity; yet the "Permo-Carboniferous" and Pleistocene glacial epochs were preceded by vulcanism.

The conclusion, therefore, seems to me unavoidable that the hypothesis postulated on an increase or decrease of the amount of carbon-dioxide in the atmosphere can not be regarded as a major factor in controlling glaciation. That it may have at times been a minor contributing factor is not only possible but quite probable.

Transportation theory.—In attempting to account for the presence of the great variety of plant remains now found in Arctic and sub-Arctic regions, it has been boldly asserted by some writers that they have been

drifted by marine currents to the places where they now are. It is of course well known that seeds and fruits of various kinds may be transported vast distances by ocean currents, and deep dredging by Agassiz and others off the American coasts has disclosed the presence on the sea bottom of plant debris, such as wood, branches, leaves, and seeds in various stages of decay. In some instances these remains were fairly abundant at a distance of 1,100 to 1,200 kilometers from shore, which corresponds to about 10 degrees of latitude.

But the plants in the Arctic regions fall within a quite different category, as they exhibit unmistakable evidence of having been deposited in fresh water. Nathorst [43] has recently published a paper in which he describes fully the depositional conditions under which the plants were entombed. The deposits range in age from Devonian to Eocene, and the plants occur often in shales overlying coal and are often underlain by clays filled with rootlets and into which the plants, roots, and stems, penetrate. There is little or no evidence of sorting by water, there often being branches, leaves of various sizes, and fruits, evidently from the same tree, all being in frequent association with Unios and other fresh-water shells. The matter may be considered as settled, that whatever the explanation of the climatic conditions which permitted their growth, full account must be taken of the fact that they undoubtedly grew at or very near the places where they are now buried.

Reversal of deep-sea circulation.—Some years ago Prof. T. C. Chamberlin [44] advanced a proposition, later strongly indorsed by Willis,[45] that the present deep-seated equatorward circulation of cold oceanic waters is abnormal, and that the more normal condition is a poleward movement of warm, highly saline waters in the depths instead of at the surface. This hypothesis was advanced to explain in perhaps major part the polar geniality of climate that geologic and paleontologic evidence shows conclusively to have occurred again and again in the ages before the Pleistocene. Under present conditions the density of polar waters is due primarily to cold, and this density may be increased by the forcing out of salts from the superficial layers by freezing; the absence of large rivers also contributes to the same end. If the polar cold could be ameliorated, obviously these influences would be moderated. Similarly, at the present time the waters in the equatorial regions are evaporated

[43] A. G. Nathorst: Fossil floras of the Arctic regions as evidence of geological climate. Geol. Mag., new ser., vol. 8, 1911, pp. 217-225.

[44] T. C. Chamberlin: On a possible reversal of deep-sea circulation and its influence on geologic climates. Jour. Geology, vol. 14, 1906, pp. 363-372.

[45] Bailey Willis: Science, new ser., vol. 31, 1910, p. 245.

and warmed and "rendered light because warm, yet heavy because saline." In the matter of actual density the equatorial waters are lighter than the polar waters, but the balance is very small, "and," says Willis, "were the polar waters less chilled or more freshened, or both, the equatorial waters would be heavier, and the reversed circulation suggested by Chamberlin must result."

As thus presented, it must be confessed that this hypothesis seems reasonable, and if it could be proved would be of weight in accounting for the presence of tropical or subtropical vegetation in polar lands; but it was reserved for Dr. E. O. Ulrich to point out its utter failure to explain the occurrence of the same marine faunas in the polar regions that are found in temperate and tropical zones. On this point Ulrich [46] says:

"In the first place these faunas, with very few exceptions, are all littoral or near-shore faunas, and their migration, whether in the oceanic or continental basins, are almost confined to the shore and bottom of the shallow seas in which they thrived. With organisms so sensitive as these to changes in temperature and depth, extensive migration under any but equable climate and bathymetric conditions would have been highly improbable, if not impossible. As corals and other animals that are now restricted to warm waters did so migrate, we must assume either that at such times mild climates prevailed or that in ages preceding the present these organisms were not affected by changes in temperature—a conclusion altogether repugnant to the geologist. Assuming that they were then as now as sensitive to temperature changes, their fossil occurrence in all latitudes must be accepted as proving at least occasional times of universally mild climates—that is, such conditions prevailed in at least the relatively brief geologic ages of which we have a marine sedimentary record in the boreal basins. . . .

"Now, according to the theory of reversed circulation, warm waters sank in the equatorial zone and reappeared at the surface in the polar regions. Could they have carried the littoral warm-water faunas with them? Manifestly, no. Or, could these faunas have migrated in their usual manner along the shore? Again we must say no, since the hypothesis requires a southward movement of cool superficial waters, which would have effectually barred shore migration." . . .

Ulrich finally concludes as follows:

"It becomes questionable then if reversal of oceanic circulation was ever an important factor in faunal distribution. Indeed, we may go further and doubt if actual reversals ever occurred."

If for the moment we accept this postulate of a reversal of oceanic circulation, what effect may it be presumed to have on plant distribution?

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[46] E. O. Ulrich: Revision of the Paleozoic systems. Bull. Geol. Soc. Am., vol. 22, 1911, p. 354.

It might to a certain extent facilitate the equatorward migration of floras that originated within polar circles, but would it not soon erect a cold, perhaps impassable barrier in middle latitudes? That is, if the waters were warmed in the equatorial region and sank to the bottom to emerge in polar areas, they would begin to flow equatorward, gradually losing heat until somewhere in middle latitudes, and before they again came under the warming influences of the equatorial region there would be a point of maximum cold. Thus as a bar to the free interchange of floras between opposite high latitudes, such as undoubtedly occurred, there would be erected three barriers, two cold areas in opposite middle latitudes, separated by a warm area in the equatorial region.

The ascertained facts of plant distribution will not tolerate any such interpretation, and therefore it is much to be doubted that such reversal did or could have taken place.

There is also another point that may be urged against this theory of reversed circulation. The terms of this hypothesis call for a heating area in the equatorial region, and this in turn implies a solar control of terrestrial temperatures similar to that now obtaining. As already pointed out again and again, this could only result in a zonal distribution of temperatures which would seemingly nullify the ameliorating effect that might be brought about by warm waters rising within the polar circles.

Volcanic dust as a climatic factor.—Benjamin Franklin was one of the first, perhaps the first, to call attention to the possibility of volcanic dust as a factor in the production of climatic changes. It seems that during the summer of 1783 there was a constant fog over all of Europe and most of North America, and the winter of 1783-84 was unusually severe. He noted that Hecla, in Iceland, and adjacent volcanoes were in active eruption, and suggested this as a possible cause of the cloudiness and hence of the lowered temperature.

It is only in recent years, however, that accurate observational data have been available on which to base a dependable conclusion as to the possible effect of volcanic dust particles in the upper air in shutting off the sun's rays. W. J. Humphreys [47] especially has published several papers on this subject. It is now possible to measure the size of volcanic dust particles with reasonable accuracy and to determine their time of fall. He states that in middle latitudes the temperature of the atmosphere becomes substantially constant at an average elevation of about 11

[47] W. J. Humphreys: Volcanic dust as a factor in the production of climatic changes. Washington Acad. Sci. Jour., vol. 3, 1913, pp. 365-371.

kilometers (36,000 feet). "This is, therefore, the upper limit of distinct vertical convection and of cloud formation."

All dust, from whatever source, is quickly washed out of the lower or cloud region by rain or snow, but such as may happen to reach the upper or isothermal region of the atmosphere continues to drift there until it is brought down by gravity to the level of passing storms. In accordance with recently made measurements on the terminal velocity of falling globules, it appears that it may take from one to four or more years before these dust particles return to the earth. In the meantime they drift out from whatever source into a thin veil, "covering perhaps the entire earth."

With these data it is possible to calculate the comparative action of volcanic dust on terrestrial and on solar radiations. According to Humphreys, it is "roughly thirtyfold more effective in shutting solar radiation out than it is in holding terrestrial radiation in. Therefore, a veil of volcanic dust must produce in inverse greenhouse effect, and, if long continued, should perceptibly lower an average temperature." He concludes as follows :

"From the above it appears quite certain that volcanic dust can lower the average temperature of the earth by an amount that depends on the quantity and duration of the dust, and that it repeatedly has lowered it certainly from 1° F. to 2° F. for periods of from a few months to fully three years."

Humphreys gives a list of the most noted volcanic eruptions from 1750 to 1912, and, so far as can be gathered from the often meager historical data, each, with a single exception, was followed by a markedly cold period.

In the summer of 1912 Abbot and Fowle[48] conducted a series of observations at Bassour, Algeria, and at Mount Wilson, California, on the effect on solar radiation of the volcanic dust believed to have been derived from the eruption of Mount Katmai, Alaska, in the early part of June, 1912. The haziness due to this cause was first noted in Algeria on June 19 and at Mount Wilson on June 21, and continued for more than three months, when the observations terminated. These authors conclude that this veil of volcanic dust decreased the heat available to warm the earth by about 10 per cent of the solar constant of radiation. They write as follows:

"It might be expected that if so great a decrease as this should continue indefinitely, the mean temperature recorded at meteorological stations would

[48] C. G. Abbot and F. E. Fowle: Volcanoes and climate. Smithsonian Misc. Coll., vol. 60, no. 29, 1913, pp. 1-24.

thereby be lowered by about 7° C. But it is not certain that the effect of this considerable diminution of heat was not counteracted by some change in the average cloudiness, or in the nocturnal radiation of the earth to space. It is conceivable that the cloud of haze prevented the escape of radiation of the earth to space in the same manner that it prevented the incoming of radiation from the sun to the earth, so that the decrease of heat available to warm the earth may have been in part or in whole compensated by a decrease in the rate of escape of heat from the earth, owing to the presence of the haze."

Although further and perhaps more exact observational data may be required to determine accurately the several factors involved, it appears to have been demonstrated with a remarkable degree of certainty that the presence of a veil of volcanic dust in the higher atmosphere may have an appreciable effect in decreasing solar radiation, and hence in reducing the amount of the sun's heat that reaches the earth. From the historical record, which covers only about 150 years, it appears that practically all considerable volcanic eruptions have been followed by cold or cooler temperatures. It is therefore assumed that the action was similar in past geologic ages; but whether it is now or has ever been sufficient to initiate glaciation may well be doubted, though it may well enough have been a minor contributing factor.

VIEWS OF BARRELL

It appears to be the conviction of many geologists that the world-wide mild climates of earlier geologic ages, together with middle latitude glaciation, etcetera, may have resulted from the combination of a number of local factors rather than from a single compelling cause. For example, Barrell writes me as follows:

"I am inclined to think that a number of fundamental factors have been involved. The earth now has a very pronounced relief with high mountain ranges and lack of shallow seas. The high mountain ranges comb out the moisture from the air. Less moisture means cold continental climates. General coldness reduces evaporation and the smaller water area also results in less evaporation. In former ages a greater evaporation area and lesser mountains would result in far higher normal humidity for the whole earth. Rain would result from a greater degree of supersaturation, chiefly in higher latitudes, and its precipitation would tend to keep the temperature high by giving up the latent heat of the water vapor. Warm waters and cloudy skies would aid in giving a winter mildness of climate. We have that now prevailing in western Ireland, western Patagonia, and certain other regions with latitude over 50°. The mildness and moistness of climate permit in both of those very rainy regions extreme luxuriance of vegetation. To account for mild polar climates these conditions would have to be more wide-spread and reach 30° farther from the equator. The results would be helped out by a perpetual

cloud mantle through the winter over such high latitudes resulting from the air being colder than the water."

Barrell also thinks that the problem is made easier of solution if there can be found evidence of the truth of the reversal of deep oceanic circulation, but certain of the facts that seem to offer a fatal objection to this view have already been presented (page 559).

To return for a moment to the views expressed by Barrell: It is easy to believe that with a low land-mass and broad, shallow, epicontinental seas the temperature would be somewhat raised, thus inducing greater evaporation, greater cloud formation and rainfall, and in the end a milder, more equable climate; but it seems to me difficult to believe that this would be of sufficient importance and magnitude to account for the varied phenomena that must be explained, especially as it appears to be predicated on the currently accepted theory of solar control of earth temperatures. The equable moist climates of the regions cited, Ireland and Patagonia, must in part be due to topographic conditions and in part to ocean currents, and any attempt at a poleward extension of these conditions to cover the 30 degrees between these localities and the poles would seem to present insuperable difficulties, especially when we consider the vast eons of time that must be accounted for in the ages before the Pleistocene. Therefore, it seems to me highly improbable that the factors called into play could have been of sufficient magnitude to have caused and maintained polar geniality, such as happened again and again. Still less does it seem that they could account for *sealevel* glaciation in middle and equatorial latitudes such as that of the "Permo-Carboniferous."

Summary and Conclusions

Now we have come to the point where it is proper to ask what progress, if any, we can presume to have made toward a solution of the several problems connected with the study of geologic climates. The various hypotheses and theories have been passed in a more or less critical review, and it is believed that a certain amount of chaff has been cleared away, thus laying a possible foundation for an acceptable explanation; but probably it would be altogether too much to claim that any hypothesis has been so far advanced that it is likely to receive universal acceptance. Barrell, when confronted by a somewhat similar interrogation, states flatly that "the depths of geologic time leave us face to face with the unknown."

To my mind, however, the case does not seem quite so hopeless. The facts that have been presented regarding the warm oceans of much if not

all of recorded pre-Pleistocene time seem to me to present a very strong presumptive case for a source of heat supplied by the earth itself. I am, of course, perfectly well aware that this view is counter to the pronouncement of the physicists and mathematicians, who are very emphatic in their opinion that the earth could never have supplied more than a small increment of the heat that is obviously called for. On the other hand, it seems to me absolutely impossible, from the data as presented in the foregoing pages, that the sun could have supplied the heat requisite to warm the early oceans. We are told that at the present time the sun supplies more than 2,000 times as much heat as is supplied by the earth itself; yet since Pleistocene time, when the present system of solar control is believed to have been established, it has not been able to warm the oceans as they were certainly warmed in pre-Pleistocene time. Furthermore, solar control is fatal to non-zonal climates, polar geniality, and tropical or subtropical glaciation. If the sun was the dominant factor in maintaining temperatures on the earth during all recorded geologic time, how or why did it fail in Pleistocene time? I can not escape the conviction that more weight must be attached to the contention that the earth itself has supplied a greater amount of heat than is now admitted to be possible. I do not see how the ascertained facts can otherwise be explained. Whether this heat came from the original earth heat, or from some augmented form of radioactivity, or from a combination of both sources, I am not prepared to say. If the mathematicians and physicists had always been right in their pronouncements on earth history, we might have more faith; but, to mention only one recent instance, after the experience in the fallibility of these arguments in determining the age of the earth, which has been so completely upset by the newly discovered factor of radioactivity, it is at least unwise or unsafe to put a too rigid dependence on them. As Huxley once said:

> "Mathematics may be compared to a mill of exquisite workmanship, which grinds you stuff of any degree of fineness; but nevertheless what you get out depends upon what you put in; and as the finest mill in the world will not extract wheat-flour from peascods, so pages of formulæ will not get a definite result out of loose data."

Therefore, it seems to me to be well within the limit of possibility that there may be factors in this problem of earth heat that are not properly evaluated or are unsuspected or undetected which may vitiate or modify previous results.

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PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY

COAL MEASURES OF MARYLAND[1]

BY CHARLES K. SWARTZ, W. ARMSTRONG PRICE, AND HARVEY BASSLER

(Read before the Paleontological Society, December 28, 1918)

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[1] Manuscript received by the Secretary of the Geological Society August 2, 1919.
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Entered in the Proceedings, this volume, page 154, as "Stratigraphy and correlation of the Coal Measures of Maryland."

Introduction

AREA

The Coal Measures are found in Allegany and Garrett counties, Maryland, situated in the western part of the State, where they underlie a large part of the region between the Alleghany front and the West Virginia-Maryland State line. The strata occupy three major structural troughs whose axes trend northeast-southwest, parallel to the trend of the mountains. The most westerly trough is called the Lower Youghiogheny, or Friendsville, basin. The middle basin is divided into two parts by a transverse minor anticline, thus forming the Upper Youghiogheny basin on the southwest and the Castleman basin on the northeast. The eastern trough is cut into two parts by the Potomac River, which turns

across it at Piedmont, the southern extension of the basin being known as the Upper Potomac basin and the northeastern as the Georges Creek basin. The relations of these basins are shown in the accompanying map.

The investigation of the area under consideration presents many difficulties. Its surface is mountainous and much of it is heavily forested. The rocks have steep dips and are buried at many places under deep overwash. Much of the region is little dissected. Trustworthy drill records were entirely lacking in the chief coal-producing area, the Georges Creek basin, when this investigation was undertaken.

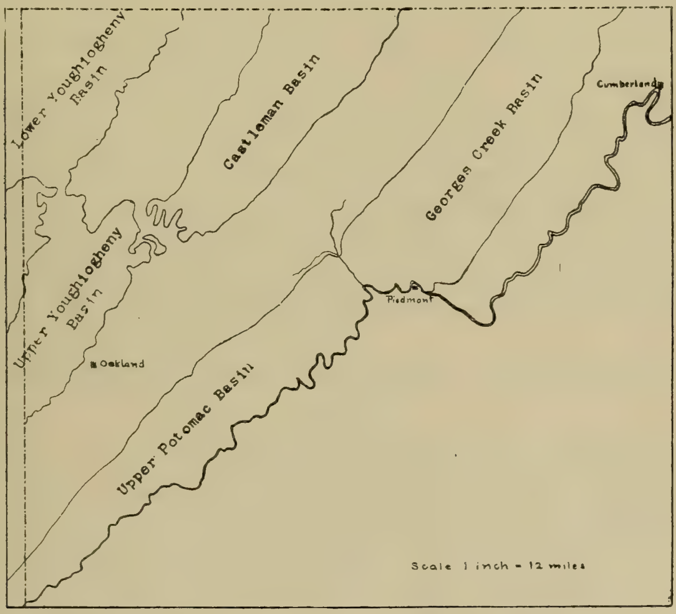

FIGURE 1.—*Map of the Coal Basins of Maryland*

EARLIER INVESTIGATION

The Coal Measures of Maryland have been studied in greater or less detail by many able and talented geologists in the past, including Tyson, I. C. White, Darton, Taft, Prosser, O'Harra, Clark, Martin, Stose, and various members of the Maryland Geological Survey. The coal beds have also been examined by mining engineers who have been associated with the various coal companies of the State. The authors feel that conclusions which differ from those obtained by such able workers should be presented with great reserve.

PRESENT INVESTIGATION

The senior author began the study in order to rectify simply a few minor details, but soon became convinced that the problem demanded fundamental investigation. He accordingly invited Dr. W. A. Price, Jr., and Dr. Harvey Bassler to assist him in the work, and feels very fortunate in enjoying their cooperation. Dr. Price has made a critical study of the marine faunas of the Carboniferous of Maryland and adjoining areas and Dr. Bassler is engaged in the monographic study of the Carboniferous flora of the State. A brief synopsis only of the results obtained will be given at this place, awaiting fuller presentation in a forthcoming monograph upon the Carboniferous of Maryland which will be published by the Geological Survey of Maryland.

Dr. Price has contributed the study of the faunas upon which the correlations so largely rest. Dr. Bassler has given valuable data for the determination of the Pottsville-Allegheny boundary derived from the study of the flora. Both of these workers have cooperated with the senior author in the examination and measurement of many sections. The senior author is responsible for the stratigraphic results and the general interpretation of the relations here presented.

Part I. Stratigraphy of the Coal Measures, by Charles K. Swartz [2]

IN GENERAL

It will suffice for the purposes of this discussion to give simply an annotated columnar section of the Coal Measures of Maryland. Since the most complete section is observed in the Georges Creek basin, the sequence of strata there found will be described, reserving a fuller discussion of the stratigraphy of the Coal Measures of Maryland for a subsequent publication.[3]

The Coal Measures of Maryland conform to the following divisions: [4]

Permian System

Dunkard Series.

Carboniferous System

Pennsylvanian (Upper Carboniferous) division.

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[2] The identification of the faunas is by W. Armstrong Price.

[3] The new members of the Coal Measures of Maryland listed in this paper will be described in a report on the Coal Measures of Maryland shortly to be published by the Maryland Geological Survey.

[4] All sections are described in descending order.

Monongahela formation.
Conemaugh formation.
Allegheny formation.
Pottsville formation.
Unconformity.

POTTSVILLE FORMATION

Character and thickness.—The Pottsville formation of Maryland consists of massive sandstones and conglomerates interbedded with shales and lenticular beds of coal. The lower beds are locally absent, owing to the pronounced unconformity that limits it below. The entire formation thickens southwestward by the successive appearance of lower and lower beds in that direction.

The upper limit of the Pottsville is questionable. If the lithological character of the sediments be the determining factor, then the Mount Savage sandstone, and perhaps also the Westernport sandstone, should be referred to the Pottsville formation, since they resemble the sediments of the latter formation. If the fossil flora be the determining criterion, then, according to the work of Harvey Bassler, the base of the Allegheny formation must be drawn beneath the lower Mount Savage coal, as has been done in this work.

As thus defined, the thickness of the Pottsville formation in Maryland varies from 100 to 250 feet.

Members.—It comprises the following members in descending order:

Homewood sandstone—Sampson Rock sandstone. Thick and massive sandstone, locally conglomeratic. Well exposed at Sampson Rock west of Frostburg.
Upper Mercer shale and fauna.
Upper Mercer coal—local.
Lower Mercer coal—local.
Upper Connoquenessing sandstone.
Quakertown shale and fauna.
Quakertown coal.
Lower Connoquenessing sandstone.
Sharon coal—local.
Unconformity.
Underlying formation—Mauch Chunk red shale.

Faunas.—A conspicuous feature of the section is the occurrence of two brackish water faunas, which have been termed the Upper Mercer and Quakertown faunas in the preceding table. The Upper Mercer fauna is meager and has been observed at but few localities. The Quakertown fauna is more persistent and has been recognized toward the southwest

in West Virginia. It was described as the Quakertown fauna by Reger in his report upon the geology of Barbour, Upshur, and western Randolph Counties, West Virginia.[5]

ALLEGHENY FORMATION

Character and thickness.—The Allegheny formation consists of interbedded shale and sandstone and bears a number of important seams of coal. Its lower beds are like those of the Pottsville formation, with which they might well be united lithologically. They contain, however, an abundant flora which shows that they are of Allegheny age. The thickness of the formation varies from 240 to 275 feet.

Members.—It contains the following members in descending order:

Upper Freeport coal—Davis coal.
Bolivar fireclay.
Upper Freeport sandstone.
Lower Freeport coal—Barrelville coal.
Montell sandstone.
Montell rider coal.
Upper Kittanning ("Lower Freeport") coal—Montell coal.
Little Montell coal—local.
Mount Savage iron ore—Johnstown iron ore ?
Hardman fireclay ("Furnace clay").
Piney Mountain coal.
Westernport sandstone.
Middle Kittanning coal—Luke coal.
Middle Kittanning clay—Luke clay.
Ellerslie sandstone.
Lower Kittanning coal—Ellerslie coal.
Lower Kittanning fireclay—Ellerslie fireclay.
Mount Savage sandstone.
Scrub-grass coal ?—Upper Mount Savage rider coal.
Clarion coal ?—Upper Mount Savage coal.
Clarion fireclay ?—Mount Savage fireclay.
Brookville coal ?—Lower Mount Savage coal.

The correlation indicated in the above list differs from that formerly used in the Georges Creek Valley, as shown in the chapter on correlation.

CONEMAUGH FORMATION

Character and thickness.—This formation consists of interbedded shale, sandstone, limestone, and lenticular coal seams. The most characteristic feature of the Conemaugh of Maryland is the presence of red

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[5] W. Va. Geol. Survey, Barbour and Uushur counties and western portion of Randolph County, 1918, p. 273.

beds, which discriminate it from the Allegheny, and of marine limestones, which separate it from the Monongahela formation. Its numerous coal seams are also more lenticular and less persistent than those of the formations mentioned.

The Conemaugh formation attains a thickness of 900 feet in the Georges Creek Valley.

Members.—It contains the following members in descending order:

Morantown coal—split from base of Pittsburgh coal.
Upper Pittsburgh limestone.
Lower Pittsburgh standstone.
Little Pittsburgh coal.
Lower Pittsburgh limestone.
Second Little Pittsburgh coal.
Connelsville sandstone.
Franklin rider coal.
Franklin coal ("Dirty Nine-foot" coal).
Lonaconing sandstone.
Upper and Lower benches of Lonaconing coal.
Hoffman sandstone.
Upper and Middle Hoffman coals.
Hoffman limestone.
Lower Hoffman coal.
Clarysville sandstone.
Upper bench of Clarksburg limestone.
Upper and Lower Clarysville coals.
Lower bench of Clarksburg limestone.
Morgantown sandstone—massive, locally conglomeratic.
Wellersburg rider coal.
Wellersburg coal—Twin coal.
Barton rider coal.
Barton sandstone.
Barton coal ("Elk Lick" coal).
Barton limestone.
Upper Grafton sandstone—massive.
Federal Hill coal.
Lower Grafton sandstone.
Upper Ames limestone and fauna.
Harlem rider coal.
Lower Ames limestone, shale, and fauna.
Harlem coal.
Ewing limestone.[6]
Pittsburgh red shale.
Saltsburg sandstone—massive, locally conglomeratic.

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[6] This is called the Ewing limestone in the reports of the West Virginia Geological Survey. According to Condit (Bull. 17, Ohio Geol. Survey, 1912, p. 37), the true Ewing limestone lies *below* the Pittsburgh red shale.

Maynadier coal—Upper Bakerstown coal.
Albright limestone.
Friendsville black shale and fauna—Cambridge fauna ?
Thomas coal—Lower Bakerstown coal.
Meyersdale red shale.
Buffalo sandstone.
Brush Creek rider coal.
Brush Creek limestone, shale, and fauna.
Brush Creek coal.
Irondale limestone.
Corinth sandstone.
Thornton clay, upper bench.
Mahoning red shale.
Gallitzin coal.
Thornton clay, lower bench.
Mahoning limestone.
Upper Mahoning sandstone—massive.
Piedmont coal.
Lower Mahoning sandstone—massive.

Faunas.—Among the most conspicuous features of the Conemaugh formation of Maryland are three marine faunas termed the Brush Creek, Friendsville (Cambridge ?), and Ames in the above list. The Brush Creek limestone and shale contain a rich fauna, including many *Chonetes verneuilianus, Bulimorpha nitidula,* etcetera. The Ames limestone forms lenticular nodules in black shale, both shale and limestone abounding in fossils, including *Ambocœlia planoconvexa, Chonetes granulifer* (typical form), and *Derbya crassa.* Shells of these three species constitute a large part of the limestone at many places. Associated with them are many other species.

The Friendsville shale bears a meager fauna (Cambridge fauna ?) in the Georges Creek Valley, where it has a brackish water aspect. It contains an increasing number of marine species westward, where it includes *Productus cora, Pustula nebraskensis, Derbya crassa,* etcetera.

A fourth fauna is found a short distance above the Lower Brush Creek fauna, in the western sections, where it contains *Spirifer cameratus, Chonetes verneuilianus, Productus cora,* etcetera. It appears to occupy the position of the Upper Brush Creek fauna of Ohio.

MONONGAHELA FORMATION

Character and thickness.—This formation consists of interbedded shale, sandstone, and limestone and contains a number of important seams of coal, including the great Pittsburgh seam. As defined in the

past, in Maryland, the thickness of this formation is about 250 feet. It is not improbable that it should be made to include part of the strata referred to the overlying Permian—a problem awaiting further investigation.

Members.—It comprises the following members in descending order:

Waynesburg coal ?
Waynesburg limestone.
Uniontown sandstone.
Uniontown coal ?
Benwood limestone.
Upper Sewickley sandstone.
Upper Sewickley coal.
Lower Sewickley sandstone.
Lower Sewickley coal ("Tyson coal").
Sewickley limestone.
Cedarville sandstone.
Redstone coal, upper bench.
Redstone sandstone.
Redstone coal, lower bench.
Upper Pittsburgh sandstone.
Pittsburgh coal.

The Permian system is represented in Maryland by the Washington and Green formations, which are preserved only in a few small areas, on the tops of the highest hills, where they are little exposed. They are without commercial coals and have been but little studied. Their further discussion will be reserved for a later publication.

TABLE SHOWING GEOLOGICAL AND GEOGRAPHICAL DISTRIBUTION OF MARINE SPECIES

The following table contains a list of the marine species found in the Coal Measures of Maryland and gives their geological range and distribution in other parts of the Appalachian basin. It is furnished by W. Armstrong Price.

SPECIES.	MARYLAND.				PENNSYLVANIA.				WEST VIRGINIA.		
	Brush Creek.		Cambridge.	Ames.	Brush Creek.	Cambridge.	Woods Run.	Ames.	Brush Creek.	Cambridge.	Ames.
	Lower.	Upper.									
COELENTERATA—Anthozoa											
Lophophyllum profundum (Edwards and Haime)	r				x	x	c	x	a		x
MOLLUSCOIDEA—Bryozoa											
Rhombopora lepidodendroides Meek		?		x					c	c	x
MOLLUSCOIDEA—Brachiopoda											
Lingula carbonaria Shumard	c	c	r		x				x	x	x
Orbiculoidea missouriensis (Shumard)				r		x			x	x	x
Crania modesta White and St. John				r				x			
Derbya crassa (Meek and Hayden)	a		r	aa	x	x	x	aa	c	x	a
Chonetes granulifer Owen			r	aa	x	x		aa	x		aa
Chonetes granulifer, small var	a								c		
Chonetes verneuilianus Norwood and Pratten	c	a		r	x	x			c	a	
Productus cora d'Orbigny	c	c	x	c	x	x	x	x	a	a	c
Productus pertenuis Meek		r		c	x			x	c	c	c
Productus semireticulatus Martin				r	x	x		x		x	x
Pustula nebraskensis Owen	c		r	a	x	x	x	x	a	a	a
Pustula symmetrica McChesney				r					a	c	
Marginifera wabashensis (Norwood and Pratten)	x			r	x	x		x			
Rhipidomella pecosi (Marcou)				r				x			x
Spirifer cameratus Morton		?			x	x		x	x	a	x
Squamularia perplexa (McChesney)				r							
Ambocœlia planoconvexa (Shumard)		r	r	aa	x	x		aa			aa
Composita girtyi Raymond		x	r								
Composita subilita (Hall)		r			x	x		x	a	a	x
MOLLUSCA—Pelecypoda											
Solenomya anodontoides Meek	c	r	r	x					x	?	
Solenomya radiata (Meek and Worthen)	r			x					x		x
Prothyris elegans Meek	c			c					x		c
Solenopsis solenoides (Geinitz)	c	r		x					x		x
Chœnomya leavenworthensis (Meek and Hayden)				x					x		
Edmondia gibbosa (McCoy)			r	c							x
Edmondia ovata Meek and Worthen	r			x					x		
Edmondia reflexa Meek	x	r		x					x		
Edmondia scutum Price	x			x							x
Nucula anodontoides Meek	c			a					c		a
Nucula parva McChesney	a	r	x	a					c		aa
Anthraconeilo taffiana Girty	c			a					x		a
Leda arata (Hall)	c	r		a	?	?					
Yoldia propinqua Meek	r			x							x
Parallelodon obsoletus (Meek)	r			x				x	x		c
Aviculipinna americana Meek	r			r					x		x
Aviculipinna nebraskensis Beede	r			x							x

SPECIES.	MARYLAND. Brush Creek. Lower.	MARYLAND. Brush Creek. Upper.	MARYLAND. Cambridge.	MARYLAND. Ames.	PENNSYLVANIA. Brush Creek.	PENNSYLVANIA. Cambridge.	PENNSYLVANIA. Woods Run.	PENNSYLVANIA. Ames.	WEST VIRGINIA. Brush Creek.	WEST VIRGINIA. Cambridge.	WEST VIRGINIA. Ames.
Pteria ohioense (Herrick)	r										
Monopteria marian White				x							
Pseudomonotis equistriata (Beede)				r							
Myalina perniformis Cox				x							x
Myalina subquadrata Shumard				c							c
Myalina swallowi McChesney				r							
Schizodus affinis Herrick				x					?		x
Schizodus cuneatus Meek?	?			?	x	x			x		
Schizodus ulrichi Worthen	?			x							x
Aviculipecten mecoyi Meek and Hayden				x							
Aviculipecten pellucidus Meek and Worthen	x								c		
Aviculipecten rectilaterarius (Cox)	c	c		c							c
Acanthopecten carboniferus (Stevens)				x	x	x			c	x	c
Deltopenten occidentalis (Shumard)	c		x	a	x			x	a	x	a
Lima retifera Shumard			r	r					x		x
Modiola ? subelliptica Meek	r			x							
Allerisma terminale Hall	x		?	c	x	x		x	x		c
Astartella concentrica (Conrad)	a		r	a	a			x	a		x
Pleurophorella papillosa Girty	r			r							
Pleurophorus sp. nov				r							
Pleurophorus tropidophorus Meek	x			c							
Pleurophorus tropidophorus aff. *occidentalis* Meek and Hayden				r					x		a
MOLLUSCA—Gastropoda											
Clavulites howardensis Girty	x			?							
Solenospira ? sp. nov	r										
Pleurotomaria (Orestes) *intertexta* Meek and Worthen			r	c							a
Phanerotrema grayvillense (Norwood and Pratten)	a		r	a	x			x	c		a
Trepospira depressa (Cox)	r				x	x					
Worthenia tabulata (Conrad)	x			r	a						
Bellerophon crassus var. *wewokanus* Girty	c		r	c							x
Pharkidonotus percarinatus (Conrad)	a		r	x	a	x		x	c		x
Pharkidonotus percarinatus var. *tricarinatus* (Shumard)	c		r	c					x		a
Bucanopsis perlata (Conrad)	x			c					x		a
Bucanopsis kansasensis (Shumard)				x							x
Euphemus carbonarius (Cox)	a		r	a	a			x	c		aa
Patellostium montfortianum (Norwood and Pratten)	a	r	r	a	a	x		x	x		aa
Schizostoma catilloides (Conrad)	a		r	c	a	x		x	c		a
Naticella ? transversa Beede?	r										
Bulimorpha nitidula (Meek and Worthen)	a				x	x			a		
Sphærodoma brevis (White)			r	c							x

SPECIES.	MARYLAND.				PENNSYLVANIA.				WEST VIRGINIA.		
	Brush Creek.										
	Lower.	Upper.	Cambridge.	Ames.	Brush Creek.	Cambridge.	Woods Run.	Ames.	Brush Creek.	Cambridge.	Ames.
Sphærodoma fusiformis (Hall)?	x			r					?		
Sphærodoma primogenia (Conrad)	x			x	x			x			x
Sphærodoma primogenia var. nov	x			r							x
Sphærodoma ventricosa (Hall)	x		r	a				x			x
Zygopleura plicata (Whitfield)				x				x	x		c
Zygopleura scitula (Meek and Worthen)	r										x
Zygopleura sp. nov	r										
Zygopleura sp. nov	r										
Aclisina stevensana (Meek and Worthen)	x			r							x
Holopea aff. *micula* (Girty)				r							
MOLLUSCA—Cephalopoda											
Orthoceras colletti Miller				c					a	x	
Pseudorthoceras knoxense (McChesney)	c		r	c		x		?	a		x
Tainoceras occidentalis (Swallow)				c	x	x		x	x		x
Metacoceras dubium Hyatt ?	x			r							
Metacoceras perelegans, var. nov	?			r							
Metacocaras sculptilis, var. nov				r							
ARTHROPODA—Trilobata											
Griffithides sangamonensis (Meek and Worthen)	r								a		
ARTHROPODA—Branchiopoda											
Estheria ortoni Clarke		r	c								

PART II. CORRELATION OF THE COAL MEASURES, BY CHARLES K. SWARTZ, W. ARMSTRONG PRICE, AND HARVEY BASSLER

METHOD OF CORRELATION

Criteria employed.—The correlation of the Coal Measures of Maryland with those of other areas appears to have been based in large degree, in the past, upon three assumptions, namely, the constancy of intervals between coals, the persistence of coal structures, and the persistence of the lithological features of the strata, other than coals, over large areas. That these assumptions are not trustworthy, when unsupported by paleontological and other evidence, is readily seen when we compare the relative uniformity of marine sediments with the variability of continental deposits.

Marine deposits, as is well known, are accumulated under much more uniform conditions than continental deposits, and hence are much more constant in composition and thickness than the latter, which, in comparison to them, possess a high degree of variability. As shown by many cases, the assumption of constancy of intervals between marine sediments would be untrustworthy in regions as remote as western Pennsylvania and Maryland without independent evidence. The assumption of constancy of interval between land sediments manifestly needs still more evidence.

The assumption of constancy of structure of coal seams is practically the affirmation of the constancy of physical conditions over large areas and is open to still greater objections. The authors would, indeed, question the continuity of many coal seams over such areas. Other types of sediments are even more variable than coals.

However valuable these criteria are within short distances, they are evidently insufficient when employed over great distances unless fortified by more cogent considerations. The authors have, therefore, sought to correlate the strata by means of their contained organisms, aided by the consideration of lithology, coal structures, systematic variations of intervals, sequence of deposits, and physical conditions of sedimentation.

This study has led to the recognition of a critical series of strata which can be distinguished by these criteria, and hence can be traced throughout large areas in the northern Appalachian coal fields. They furnish the key to the correlation of the middle Coal Measures in the area under consideration.

Character of the critical series of the Lower Conemaugh.—The critical series of beds is found in the lower part of the Conemaugh formation and is characterized as follows:

Faunas.—It embraces four horizons bearing marine faunas, named in descending order:

Top.
- Ames limestone and fauna.
- Portersville limestone and fauna.
- Cambridge limestone and fauna.
- Brush Creek limestone and fauna.

Bottom.

The Ames limestone, the upper member of the series, forms lenticular beds of limestone or occurs as discontinuous limestone nodules in a dark, fossiliferous shale. It bears a profuse fauna which is characterized by containing great numbers of *Ambocœlia planoconvexa, Chonetes granu-*

lifer, typical forms, and *Derbya crassa,* associated with which are many other species. *Ambocœlia planoconvexa* is very abundant, its shells constituting a large part of the limestone at many localities. It is absent or of rare occurrence in the Brush Creek limestone at most localities east of Ohio. The Ames limestone is double at many places.

The Portersville fauna is meager and not well characterized. It is little known east of Ohio.

The Cambridge fauna, though richer and much more widely extended than the Portersville, is less profuse and apparently not so widely distributed as the Ames and Brush Creek faunas. It consists of marine species in the western sections, but is more meager eastward, where it is mingled with brackish water forms. In the Georges Creek basin it appears to be replaced entirely by brackish water species.

The Brush Creek fauna is characterized by the presence of many *Chonetes verneuilianus* associated with other distinctive though less abundant species and by the absence of *Ambocœlia planoconvexa* [7] and the typical form of *Chonetes granulifer* at most localities east of Ohio. The fauna is abundant, though less profuse on the whole than the Ames. Like the Portersville and Cambridge, it is more meager eastward, following the apparent rule that more abundant faunas extend farther east.

The Brush Creek limestone, like the Ames, is found in a lower and upper division in many places.

Lithology.—The beds of this series may also be recognized by their lithological sequence, systematically varying intervals, and the relations they sustain to the faunas over great areas. They comprise the following members in descending order:

Top.

Ames limestone and fauna { Upper division. / Lower division.
Harlem coal.
Ewing limestone.
Pittsburgh red shale.
Saltsburg sandstone.
Porterville limestone and fauna (western sections).
Coal.
Cambridge red beds.
Cambridge limestone and fauna.

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[7] *Ambocœlia planoconvexa* is cited by Condit from a number of localities in the Brush Creek of Ohio. It is, however, of rare occurrence at this horizon in the eastern sections.

Coal.
Meyersdale red beds.
Buffalo sandstone.
Brush Creek limestone and fauna {Upper division. / Lower division.}
Brush Creek coal.
Bottom.

Thickness.—The interval between the Harlem and the Brush Creek coal varies from 145 feet in Ohio to 260 feet in Pennsylvania and Maryland.

Underlying beds.—Another persistent series of beds is found below the Brush Creek coal, which may be recognized by its relation to the overlying strata throughout a large area in the northern Appalachians. It includes the following members, which follow immediately beneath the Brush Creek coal:

Top.
Irondale limestone.
Sandstone.
Thornton fireclay, upper bench.
Mahoning red beds.
Coal (local).
Thornton fireclay, lower bench.
Mahoning sandstone (massive).
Coal (local).
Upper Freeport coal—top of Allegheny formation.
Upper Freeport limestone.
Bottom.

The relations of these beds will be discussed later.

Sections of critical series of the Lower Conemaugh from Ohio to Pittsburgh, Pennsylvania.—These beds furnish a series of datum planes to which the other strata of the Coal Measures may be referred. We will now proceed to trace them in a series of sections from Ohio to Maryland, beginning on the west in Meigs County, Ohio, and passing thence eastward to the Georges Creek basin of Maryland. In this manner a basis will be laid for the correlation of the middle Coal Measures of the area under consideration. For convenience of description the sections will be grouped in three sets, comprising (1) sections from Ohio to Pittsburgh, (2) those between Pittsburgh and Maryland via West Virginia, (3) those between Pittsburgh and Maryland via western Pennsylvania.

Meigs County, Ohio. This area is near the southwestern extremity of

the outcrop of the Conemaugh in Ohio. Condit describes the following sequence in this county:[8]

Ames limestone and fauna, Harlem coal, Pittsburgh red beds, Portersville limestone and fauna, Anderson coal, Cambridge limestone and fauna, Brush Creek limestone and fauna, Brush Creek [Mason] coal.

The section displays the normal sequence, save that the Saltsburg and Buffalo sandstones are absent. The thickness of the section is 145 feet, which is less than that of the eastern sections.

Muskingum County, Ohio. This area is northeast of Meigs County. Condit describes the following general sequence in this county:[9]

Ames limestone and fauna, Harlem coal, Ewing limestone, [Saltsburg] sandstone, Anderson coal, [Albright ?] limestone, Cambridge limestone and fauna, Buffalo sandstone, Brush Creek limestone and fauna, Brush Creek [Mason] coal.

The thickness is 150 feet. The section, as shown by Condit, is clearly the same as the preceding.

Wheeling, West Virginia. I. C. White has described an excellent section furnished by a diamond drill core at Glenova, near Wheeling, West Virginia, in which the following sequence was observed:[10]

Ames limestone and fauna, Pittsburgh red beds, Saltsburg sandstone, [Portersville] limestone and fauna, coal, [Cambridge] red beds, Brush Creek limestone and fauna, Brush Creek coal.

The thickness is 210 feet. The section is manifestly a continuation of that described by Condit in Ohio.

Pittsburgh, Pennsylvania. The following generalized section is based upon a number of local sections described by Raymond[11] and upon drill records interpreted by the senior author:

Ames limestone and fauna, Harlem coal, Pittsburgh red beds, Saltsburg sandstone, coal, Cambridge limestone and fauna, Meyersdale red beds, Buffalo sandstone, Brush Creek limestone and fauna, Brush Creek coal.

The thickness is 205 feet. The section embraces the standard elements of the western area and adds to them the Meyersdale red shale,

[8] D. D. Condit: Conemaugh formation in Ohio. Bull. 17, Geol. Survey Ohio, 1913, p. 92. See plate of columnar section. The members are enumerated in descending order in all the following sections.

[9] D. D. Condit: Conemaugh formation in Ohio. Bull. 17, Geol. Survey Ohio, 1913, p. 146. Names in brackets [ ] added by senior author.

[10] I. C. White: Report on Ohio, Brooke, and Hancock counties. W. Va. Geol. Survey, 1906, pp. xii-xv. The names of members in brackets [ ] are supplied by the senior author.

[11] Percy Raymond: Ann. Carnegie Mus., vol. v, 1908-1909, p. 173 et seq.

which is widely distributed farther east. These sections show the extension of this series eastward to Pittsburgh. Many more sections could be added if desired.

Sections of critical series of the Lower Conemaugh from Pittsburgh, Pennsylvania, to Maryland via West Virginia.—Two routes now present themselves by which the beds can be traced from Pittsburgh to Maryland, one passing through West Virginia, the other through Pennsylvania. The sections on the route through West Virginia will first be considered and afterward those connecting Pittsburgh and Maryland via western Pennsylvania.

Morgantown, Monongalia County, West Virginia. I. C. White and his associates described an excellent section at Morgantown, West Virginia,[12] which comprises all the more significant members of the series in their normal sequence, save that the Brush Creek coal was absent in the drill record cited, though present in the vicinity. It comprises the following:

Ames limestone and fauna, Harlem coal, Ewing limestone, Pittsburgh red beds, Saltsburg sandstone, coal, [Cambridge] red beds, Cambridge limestone and fauna, [Meyersdale] red beds, Buffalo sandstone, Brush Creek limestone and fauna, Brush Creek coal.

The thickness is 195 feet. The section is in manifest agreement with that at Pittsburgh, Pennsylvania.

Preston County, West Virginia. I. C. White and his associates described the following section in western Preston County,[13] 18 miles southeast of the preceding:

Ames limestone and fauna, Harlem coal, Ewing limestone, Pittsburgh red beds, Saltsburg sandstone, coal, Albright limestone, Cambridge limestone and fauna, [Meyersdale] red beds, Buffalo sandstone, Brush Creek limestone and fauna, Brush Creek coal.

The thickness is 200 feet. This section evidently embraces the same units as the preceding.

We have now traced the critical series of beds containing marine faunas in the lower Conemaugh from Meigs County, Ohio, to Preston County, West Virginia. The number of the sections described is small, but the list could have been greatly extended if desired. It is sufficient, however, to show the persistence of the beds under consideration, and

[12] I. C. White, R. V. Hennen, D. B. Reger: Geology of Marion, Monongalia, and Taylor counties. W. Va. Geol. Survey, 1913, p. 116.

[13] I. C. White, R. V. Hennen, and D. B. Reger: Geology of Preston County. W. Va. Geol. Survey, 1914. Section at Newberg, Lyon district, p. 90, and general section, pp. 113-114.

that they are recognizable throughout this wide area by their distinctive faunas, prevalent lithology, sequence, and systematically increasing intervals. The results thus far given rest upon the work of many independent investigators. Preston County, West Virginia, immediately adjoins the State of Maryland.

Upper Youghiogheny basin, West Virginia and Maryland. This basin lies both in eastern Preston County, West Virginia, and in Garrett County, Maryland, 15 miles east of the preceding locality.

The section observed in this basin [14] may be compared with that given by White and his associates in western Preston County, as follows:

West Preston County, West Virginia	*East Preston County, West Virginia-Garrett County, Maryland*
Ames limestone and fauna.	*Ames limestone and fauna.*
Harlem coal.	*Harlem coal.*
Ewing limestone.	*Ewing limestone.*
Pittsburgh red beds.	*Pittsburgh red beds.*
Saltsburg sandstone.	*Saltsburg sandstone.*
Coal.	*Coal.*
Albright limestone.	*Albright limestone.*
Cambridge limestone and fauna.	—— ——.
[*Meyersdale*] *red beds.*	*Meyersdale red beds.*
Buffalo sandstone.	*Buffalo sandstone.*
Brush Creek limestone and fauna.	*Brush Creek limetsone and fauna.*
Brush Creek coal.	*Brush Creek coal.*
Thickness, 200 feet.	Thickness, 222 feet.

The above sections include the same important beds in the same order at similar intervals, the only significant difference being the absence in the Maryland section at this point of the Cambridge limestone and fauna. The latter is found in Maryland, however, in the Friendsville area, which immediately adjoins this basin on the north, where it is well developed and in its proper position. The slight difference in intervals harmonizes with the general thickening eastward. The similarity of the lithology of the sections, the agreement of faunas, intervals and sequence, are so complete and the distance between the sections is so small that their identity is evident. This conclusion is further fortified by the agreement of the remainder of the section (see columnar sections).

Upper Potomac basin, Maryland. This basin lies 10 miles east of the Upper Youghiogheny basin, from which it is separated by the Oakland anticline.[15] The section includes the following:

[14] By Swartz and Price.

[15] The authors are greatly indebted to Mr. M. D. Kirk, of the Davis Coal and Coke Company, for the privilege of examining the records of a large number of diamond drill-holes put down by this company in the Maryland portion of the basin. The data so obtained were invaluable in interpreting the stratigraphy of the region.

Ames limestone and fauna, Harlem coal, Ewing limestone, Pittsburgh red beds, Saltsburg sandstone, [Maynadier] coal, Albright limestone, Cambridge red beds, [Thomas] coal, Buffalo sandstone, Brush Creek limestone and fauna, Brush Creek coal.

The average interval from the Harlem to the Brush Creek coal, as shown by diamond drill-holes, is 218 feet, which is in close agreement with the thickness of 222 feet in the Upper Youghiogheny basin. The underlying beds, between the Brush Creek and the Upper Freeport limestone, are also in agreement in the two basins, including [Corinth] sandstone, Thornton clay, Mahoning red beds, [Gallitzin] coal, Mahoning sandstone, [Piedmont] coal, Upper Freeport [Davis] coal, and the Upper Freeport limestone, which are found in both basins. The interval from the Brush Creek to the Upper Freeport [Davis] coal is 110 feet in the Upper Youghiogheny basin and 120 feet in the Upper Potomac.

The Davis coal is thus seen to occupy the position of the Upper Freeport coal. The Piedmont coal above it is perhaps a split from the latter seam.

The section described is in harmony, in all important members as well as in intervals, with that exposed in the Upper Youghiogheny basin, as seen by comparing the columnar sections of the two basins (shown in plate of columnar sections). The chief difference observed is the presence of the Cambridge red shale in the Upper Potomac basin and its absence in the Upper Youghiogheny basin. The identity of the sections, in all important respects, is manifest.

Sections of critical series of Lower Conemaugh from Pittsburgh to Maryland via western Pennsylvania.—We have described the sections between Pittsburgh and Maryland via West Virginia and found the critical series to extend from Ohio to Maryland via West Virginia. We will next consider the sections from Pittsburgh to Maryland via western Pennsylvania.

Freeport, Pennsylvania. The section of the Lower Conemaugh and Upper Allegheny at Freeport, Pennsylvania, is of particular interest, as this is the typical locality of the upper members of the Allegheny formation and hence determines the boundary between the Conemaugh and Allegheny formations. The following section was observed at this place: [16]

Ames limestone and fauna, Pittsburgh red beds, Saltsburg sandstone.

[16] Section by Swartz and Bassler. See chart of columnar sections for measurements of intervals.

coal, Cambridge red beds, coal, Meyersdale red beds, Buffalo sandstone, Brush Creek limestone and fauna, Brush Creek coal.

The interval between the Ames and Brush Creek limestone is 230 feet.

The Cambridge limestone and fauna were not observed by the authors at Freeport, but are reported in the proper position in the vicinity by I. C. White.[17]

The section is in full agreement with those already described. The average interval between the Brush Creek limestone and Upper Freeport coal is 115 feet (120 feet at Freeport).

Latrobe, Pennsylvania. Raymond[18] and Campbell[19] describe excellent sections in the vicinity of Latrobe which embrace the following:

Ames limestone and fauna, Harlem coal, Pittsburgh red beds, Saltsburg sandstone, Albright limestone, Buffalo sandstone, Brush Creek limestone and fauna, Brush Creek coal.

The thickness is 229 feet, which may be compared with the thickness of 230 feet at Freeport. The section agrees in its chief elements with that at Freeport.

Somerset County, Pennsylvania. The section at this place is based upon the work of Dr. G. B. Richardson, who has not only given the author his interpretations of the section, but has most generously furnished him with valuable diamond-drill records. It presents the following sequence:

Ames limestone and fauna, Harlem coal, [Ewing] limestone, Pittsburgh red shale, Saltsburg sandstone, Cambridge limestone and fauna, coal, Meyersdale red beds, Buffalo sandstone, Brush Creek limestone and fauna, Brush Creek coal.

The thickness is 261 feet. The interval from the Brush Creek coal to the Upper Freeport coal is 135 feet. This section is in full accord with the preceding.

Somerset County immediately adjoins the State of Maryland on the north.

Castleman basin, Pennsylvania-Maryland. This basin lies both in Somerset County, Pennsylvania, and in Garrett County, Maryland, thus connecting the exposures of the two States. It is distant but 15 miles from the Somerset section studied by Richardson. The following sequence was observed[20] near Meyersdale, Pennsylvania, and Grantsville, Maryland:

[17] I. C. White: Second Geol. Survey Pa., vol. Q, 1878, p. 24.
[18] Ann. Carnegie Mus., vol. 5, 1908-1909, p. 166 et seq.
[19] Latrobe Folio, U. S. Geol. Survey., No. 110.
[20] By Swartz and Price.

Ames limestone and fauna, Harlem coal, Ewing limestone, Pittsburgh red beds, Saltsburg sandstone (massive), *coal, Albright limestone, Cambridge [Friendsville] shale and fauna, coal, Meyersdale red beds, Buffalo sandstone, Brush Creek limestone and fauna, Brush Creek coal.*

The interval from the Harlem to the Brush Creek coal is 260 feet, as compared with 261 feet in a diamond-drill record near Somerset, Pennsylvania. The section between the Brush Creek coal and the Upper Freeport coal is also in close agreement in the two basins, the interval between them being 115 feet in the Castleman basin and 130 feet at Somerset, Pennsylvania. The agreement of this section with that last described is so close in lithology, in position of faunas, sequence, and intervals and the distance between them (10 miles) is so small that there can be little doubt of their correlation.[21]

Georges Creek basin, Maryland. This basin lies 10 miles east of the Castleman basin, from which it is separated by the Oakland anticline. The section here exposed includes:

Ames limestone and fauna, upper and lower divisions; *Harlem coal, Ewing limestone, Pittsburgh red shale, Saltsburg sandstone*—massive; *coal, Albright limestone, Cambridge [Friendsville] shale and fauna, coal, Meyersdale red shale, Buffalo sandstone, Brush Creek limestone and fauna, Brush Creek coal.*

The average thickness is 257 feet. The interval from the Brush Creek coal to the Upper Freeport [Davis] coal is 120 feet.

As will be seen by a comparison of the columnar sections, the agreement of this section with that in the Castleman basin is so complete, embracing the same units and faunas in the same sequence, at essentially the same intervals, that their identity is manifest.

The Georges Creek and the Upper Potomac areas are part of the same structural basin, their strata are continuous, and the sections are in full agreement. We are thus brought to the same conclusion, whether we approach Maryland by way of West Virginia or via western Pennsylvania.

Persistence of critical series.—We have now described the critical series of the lower Conemaugh and found that it constitutes a clearly recognizable group, which may be traced throughout the area considered by means of its faunas, lithology, intervals, and sequence.

The Ames fauna is distinguished throughout the entire area, when normally developed, by its profusion of *Ambocœlia planoconvexa, Chonetes granulifer,* typical form, and *Derbya crassa.* This fauna is

[21] See columnar sections.

present in all the sections described and is as well developed in Maryland as elsewhere. The Brush Creek fauna is less profuse than the Ames, but is clearly traceable throughout the area by means of its diagnostic species. The Cambridge fauna, though more meager than the Ames and Brush Creek, is probably present throughout the region, being represented by brackish water forms in the eastern sections, with which are associated an increasing percentage of marine species farther west.

The lithology exhibits a definite sequence, which can be recognized and traced through all the sections. Four coals are present. Two of these, the Harlem, underlying the Ames marine limestone, and the Brush Creek, beneath the Brush Creek marine limestone, are found in most of the sections described from Ohio to Maryland. Two other coals, lying between the Saltsburg and Buffalo sandstones, are widely distributed though less persistent, being found in Ohio, at Freeport, Pennsylvania, and in Maryland. Two non-marine limestones are present. The upper of these, the Ewing, being widely distributed beneath the Harlem coal, at many localities from Ohio to Maryland. Among the most significant features of the section are the red beds. The Pittsburgh red shale is very persistent, occurring a short distance beneath the Harlem coal in nearly every section described, while the Meyersdale red shale is observable at many localities east of Pittsburgh. The Saltsburg and Buffalo sandstones are also important and persistent members of the sections described.

The columnar sections show that the members occur at intervals which vary systematically throughout the area. Beginning with an interval of 145 feet between the Harlem and Brush Creek coals, in the western section, the distance between these beds increases systematically from west to east until, in the Georges Creek Valley, it is 260 feet.

This systematic change is well shown by the columnar sections, in which the sections are placed on an east and west line. The intervals between the Harlem and Brush Creek coals are remarkably similar in the last three sections, being, as shown by the diamond-drill cores, 261 feet in the Somerset basin, 260 feet in the Castleman basin, and 257 feet in the Georges Creek basin.

Finally, the sections are close to each other, the distance from the Georges Creek basin to the Castleman basin being 10 miles; from the latter to the Somerset section 15 miles; from the Somerset section to Latrobe 25 miles; from Latrobe to Pittsburgh 30 miles; from Pittsburgh to Freeport 25 miles. The sections at Latrobe, Pittsburgh, and Free-

port have been connected by numerous intermediate sections by many independent investigators.

The strata of the Georges Creek basin are also continuous with those of the Upper Potomac basin. The distance from the latter basin to the Upper Youghiogheny basin is 8 miles; from the Upper Youghiogheny basin to the Preston County section 15 miles; from the Preston County section to Morgantown 18 miles. The section at Morgantown is again connected with the typical areas in Pennsylvania by sections studied by many independent workers.

The facts adduced show that the correlation of the series is manifest. Two conclusions follow:

1. There is a persistent eastward thickening of the Conemaugh, the formation being 350 feet thick in southeastern Ohio, 600 feet at Pittsburgh, and 900 feet in the Georges Creek Valley of Maryland. The failure to recognize this eastward thickening has led, in the past, to the assignment of the same thickness to the Conemaugh formation in Maryland as at Pittsburgh, with the consequence that a considerable part of the Conemaugh formation has been assigned to the Allegheny formation by former workers in Maryland.

2. The Davis coal of Maryland and adjacent parts of West Virginia is in the position of the Upper Freeport coal.

CORRELATION OF FORMATIONS

In general.—We have now traced a series of strata through the Coal Measures of the northern Appalachian basin which serves as a datum plane to which the other beds may be referred. We thus have a key to the correlation of the middle Coal Measures of the northern Appalachian basin. The correlation of the Monongahela will be briefly suggested, after which the relations of the underlying formations will be considered more fully.

Monongahela formation.—The upper limit of the Monongahela formation of Maryland has been placed, in the past, at the top of a thick coal situated 250 feet above the Pittsburgh seam, which has been called the Waynesburg coal. The latter coal is preserved in but a small area and its true relations need further investigation. The base of the Monongahela formation is clearly marked by the thick Pittsburgh coal, which is recognizable throughout most of the area by its character and stratigraphic relations. It furnishes an important datum plane for correlation in the northern Appalachian basin.

The suggested relations of the other members of the Monongahela formation of Maryland are indicated in the chapter on stratigraphy.

Conemaugh formation.—The Conemaugh formation is distinguished from the Allegheny formation by the presence of red beds, which make their first appearance near the base of the Conemaugh and, as shown by I. C. White,[22] constitute one of the most characteristic features of the Conemaugh. It is distinguished from the overlying Monongahela formation by the presence of marine faunas and by a lesser content of coal. The top of the Conemaugh is well defined by the base of the Pittsburgh seam. The lower limit of the formation is the top of the Upper Freeport coal of western Pennsylvania.

The base of the Conemaugh has been placed, in the past, in the Georges Creek, Upper Potomac, and Upper Youghiogheny basins of Maryland and West Virginia, at the top of a coal found about 600 feet beneath the Pittsburgh seam. That this is not the Upper Freeport coal is shown by the fact that the Ames fauna, abounding in *Ambocœlia planoconvexa, Chonetes granulifer,* and its other characteristic species is found but 75 feet above it, while the Brush Creek fauna is found *185 feet beneath* it. Just beneath this coal is found a fauna, consisting of brackish water species in the Georges Creek Valley and marine species in the western sections of the State, which occupies the horizon of the Cambridge limestone of Ohio. Red beds occur 100 to 200 feet below the coal in question. It is clear that this coal lies far above the horizon of the Upper Freeport coal, apparently occupying the position of the Anderson coal of Ohio and of the upper of two coals which lie between the Saltsburg and Buffalo sandstones in the section at Freeport, Pennsylvania. It, therefore, can not be the Upper Freeport coal.

The Davis coal of Maryland lies about 200 feet beneath the coal last named and 120 feet beneath the Brush Creek limestone and fauna. It thus occupies the position of the true Upper Freeport, which lies about 115 feet beneath the Brush Creek coal in the vicinity of Freeport, Pennsylvania, and is clearly traceable through the various sections from Freeport, Pennsylvania, into Maryland by means of its position with respect to the critical series already discussed. The Upper Freeport limestone is found in its proper position beneath this coal in the Upper Potomac and Castleman basins, extending thence westward.

The Barton coal of Maryland is not the Bakerstown, as was formerly

[22] Coal Report, West Virginia Geol. Survey, vol. ii, 1903, pp. 225-227, and vol. iia, 1908, pp. 622-624. Report on Geology of Braxton and Clay counties. West Virginia Geol. Survey, 1917, pp. 822-829.

supposed, but lies nearly 100 feet *above* the Ames limestone and is hence in the position of the coal commonly called the "Elk Lick" in neighboring areas. The persistent limestone 100 feet above the Barton coal may be correlated provisionally with the Clarksburg limestone.

The suggested correlation of the various members of the Conemaugh is indicated in the chapter on stratigraphy and will not be further considered here (see also plate of columnar sections).

It is interesting to note that, associated with the thickening of the strata, there is a great increase in the content of coal, so that the Conemaugh contains many coal seams in Maryland, where it is not a barren formation.

Allegheny formation.—The upper limit of the Allegheny formation is determined by the evidence already adduced. The lower limit, however, is open to question. The most important datum plane for the correlation of the lower members of the Allegheny formation in the typical area is the Vanport (Ferriferous) limestone. This is a thick limestone, containing a profusion of marine fossils, found about 50 feet below the lower Kittanning coal in western Pennsylvania. It extends but a few miles east of Pittsburgh. The correlation of the lower members of the Allegheny formation presents great difficulties east of the latter point, owing to the absence of a trustworthy datum plane.

An attempt has been made in the past to draw the boundary between the Pottsville and Allegheny formations in Maryland by means of changes in the character of the lithology. If this criterion be employed, the Pottsville-Allegheny boundary would undoubtedly be drawn above the Mount Savage sandstone and probably, at some localities, above the Westernport sandstone. It is manifest, however, that there is a marked variation in the lithology from place to place and it seems unsafe to determine the limits of the formation over wide areas without paleontological evidence. In view of the absence of the Vanport limestone in the eastern section, an effort has been made to draw the boundary between the Pottsville-Allegheny formations in Maryland by means of the fossil floras. With this purpose in view, extended and detailed collections of the floras have been made in Maryland and adjacent areas and also in the typical sections of the Allegheny formation of western Pennsylvania. It is impossible to review the data at this point. Suffice it to say that the conclusions reached by Harvey Bassler, who has been engaged in a critical study of this problem, indicate that the profuse flora associated with the Mount Savage coals are of Allegheny age, and that a distinct change in floras occurs a short distance beneath the latter

horizon. The Pottsville-Allegheny boundary would thus be placed beneath the Lower Mount Savage coal and above the massive Sampson Rock conglomerate. The Ellerslie coal would appear to be the Lower Kittanning coal and the Upper and Lower Mount Savage coals, the Clarion and Brookville coals respectively.[23]

The discrepancy in the position of the Pottsville-Allegheny boundary indicated by the flora and by the lithology is due, possibly, to the fact that arenaceous beds accumulated along the steeper gradients of the streams in the east, in Lower Allegheny time, while more argillaceous sediments were forming along their lower gradients in the west. If this is the case, a line drawn between the Allegheny and Pottsville formations upon the basis of lithology would rise across the strata eastward and include sediments of Allegheny age in the Pottsville formation.

The full presentation of the evidence bearing upon these points must be reserved for the discussion of the floras, which will appear in a subsequent publication.[24] The thickness of the Allegheny as thus limited is 250 to 300 feet.

Pottsville formation.—The Pottsville formation consists of massive sandstones, conglomerates, and interbedded shale, which, as shown by David White, bear a distinctive flora. As delimited in the preceding discussion, it consists in Maryland of two zones of massive sandstones separated by a shale zone. Two fossil faunas are present, consisting of a few brackish water species. The lower zone bears the same species southward [25] and appears to be definitely correlated with the Quakertown fauna of West Virginia. The upper zone is questionably placed at the horizon of the Upper Mercer fauna of Pennsylvania.[26] The Pottsville rests unconformably upon the Mauch Chunk red shale.

Conclusion and Summary

The preceding discussion shows that certain features of the Coal Measures are persistent over large areas, the beds containing the marine

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[23] That the correlation of the individual coals of the Allegheny and Pottsville formations is insecure in much of the northern Appalachian coal basin is made manifest by the examinaton of the accompanying plate of columnar sections of these formations. Lithology and intervals are insufficient, without paleontological data, for confident correlation.

[24] Monograph of the Carboniferous of Maryland to be published by the Maryland Geological Survey.

[25] W. Armstrong Price: Report on Barbour, Upshur, and the western portion of Randolph counties. W. Va. Geol. Survey, 1918, p. 786.

[26] See chapter on Stratigraphy, where the relations of the members are further discussed.

faunas in the Lower Conemaugh having a wide distribution. Associated with them are coals, red beds, fresh-water limestones, and even sandstones, which, though lenticular and discontinuous, are found at many places in the northern Appalachian coal basin.

Other features are systematically variable. Thus the Conemaugh increases in thickness eastward, being 350 feet thick in Ohio, 600 feet at Pittsburgh, Pennsylvania, and 900 feet in Maryland. The deposits are more arenaceous eastward, indicating steeper stream gradients there. The coal content also increases eastward, seven coal seams being described in the Conemaugh of Ohio, while 27 beds are found in the same limits in Maryland.

The red beds are formed at definite horizons over wide areas. They are thin in the eastern sections, but increase in number and volume westward, their development appearing to bear an inverse relation to that of the coals. Conditions favorable for the formation of red beds thus appear prejudicial to the accumulation of coal. If, as their occurrence suggests, they have climatic significance, they should have large value for purposes of correlation.

Certain Permian elements make their appearance associated with the red beds as seen in the flora, insects,[27] and the possible occurrence of a *Pareiasaurus* in West Virginia.[28] The significance of these facts needs further elucidation.

The accumulation of the sediments seems to indicate progressive crustal deformation with downwarp toward the east. If coal beds are laid down near sealevel, the conditions would appear to have been rather stable over large areas until Brush Creek time, after which, as shown by the wedgelike thickening of the Conemaugh eastward, warping became more marked, reaching a maximum before the deposition of the Pittsburgh seam.

The preceding discussion may be summarized briefly as follows:

1. A persistent series of beds containing marine faunas is recognized in the lower Conemaugh. Its faunas, lithology, sequence, and intervals are described.

2. This series is traced by means of numerous sections from Ohio to Maryland, thus laying a basis for the correlation of the middle Coal Measures of this area.

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[27] Samuel H. Scudder: Bull. U. S. Geol. Survey, No. 124, p. 12.

[28] E. C. Case: W. Va. Geol. Survey. Report on geology of Braxton and Clay counties, 1917, pp. 817-821. See also I. C. White, ibid., pp. 822-829, and E. C. Case, Ann. Carnegie Mus., vol. iv, 1908, pp. 234-241.

3. The various formations are correlated and the relations of some of the more important members considered.

4. The results thus secured are summarized in a chapter on stratigraphy.

5. Certain general conclusions are indicated.

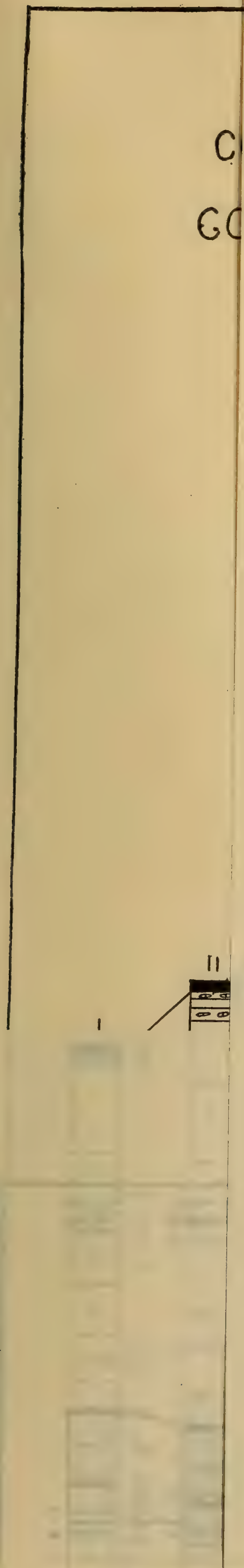
Explanation of Plates

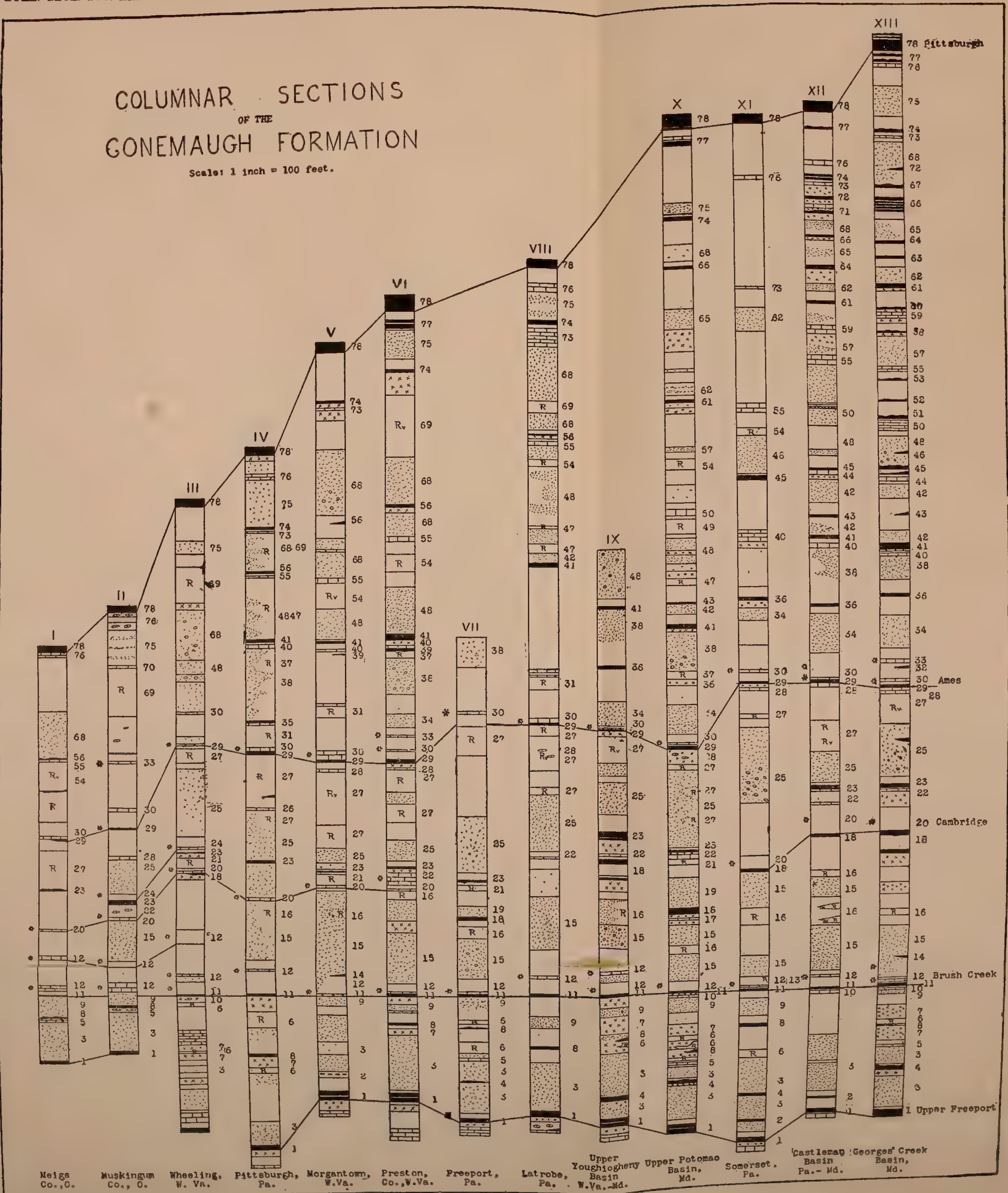
Plate 14.—*Sections of Conemaugh Formation*

Section I, Meigs County, Ohio, based on section by Condit.
Section II, Muskingum County, Ohio, based on section by Condit.
Section III, Wheeling, West Virginia, based on section by I. C. White.
Section IV, Pittsburgh, Pennsylvania, Swartz, generalized from drill records and local sections by Raymond.
Section V, Morgantown, West Virginia, based on section by I. C. White.
Section VI, Preston County, West Virginia, based on sections by I. C. White, Reger, and Hennen.
Section VII, Freeport, Pennsylvania, Swartz and Bassler.
Section VIII, Latrobe, Pennsylvania, based on sections by Campbell and Raymond.
Section IX, Section in Upper Youghiogheny Basin, Maryland, Swartz and Price.
Section X, Section in Upper Potomac Basin, Maryland, Swartz; measurement of upper 100 feet by D. B. Reger.
Section XI, Somerset, Pennsylvania, based on work of G. B. Richardson.
Section XII, Section of Castleman Basin, Maryland, Swartz and Price.[29]
Section XIII, Georges Creek Basin, Maryland, Swartz.

Numerals refer to members; R signifies red beds; Rv, variagated with red; * indicates fauna.

[29] The upper part of this section has been studied critically, in adjacent parts of Pennsylvania, by the senior author since this diagram was prepared. The results will be published in a separate paper.





SECTIONS OF CONEMAUGH FORMATION

78. Pittsburgh coal.
77. Morantown coal.
76. Upper Pittsburgh limestone.
75. Lower Pittsburgh sandstone.
74. Little Pittsburgh coal.
73. Lower Pittsburgh limestone.
72. Second Little Pittsburgh coal.
71. Third Little Pittsburgh coal.
70. Summerfield limestone.
69. Connellsville red bed.
68. Connellsville sandstone.
67. Franklin rider coal.
66. Franklin coal.
65. Lonaconing sandstone.
64. Upper bench of Lonaconing coal.
63. Lower bench of Lonaconing coal.
62. Hoffman sandstone.
61. Upper Hoffman coal.
60. Middle Hoffman coal.
59. Hoffman limestone.
58. Lower Hoffman coal.
57. Clarysville sandstone.
56. Little Clarksburg coal.
55. Upper bench of Clarksburg limestone in Maryland, Clarksburg limestone elsewhere.
54. Upper Clarksburg red bed in Maryland, Clarksburg red bed elsewhere.
53. Upper Clarysville coal.
52. Lower Clarysville coal, upper bench.
51. Lower Clarysville coal, lower bench.
50. Lower bench of Clarksburg limestone.
49. Lower Clarksburg red bed.
48. Morgantown sandstone.
47. Morgantown red bed.
46. Wellersburg rider coal.
45. Wellersburg coal in Maryland, "Elklick coal" near Somerset, Pennsylvania.
44. Wellersburg limestone.
43. Barton rider coal.
42. Barton sandstone.
41. Barton coal in Maryland, "Elklick coal" in West Virginia.
40. Barton limestone.
39. West Millford coal.
38. Upper Grafton sandstone.
37. Birmingham red bed.
36. Federal Hill coal.
35. Duquesne coal.
34. Lower Grafton sandstone.
33. Skelley limestone in Ohio, Upper Ames eastward.
32. Harlem rider coal.
31. Ames red bed.
30. Ames limestone and fauna.
29. Harlem coal.
28. Ewing limestone.
27. Pittsburgh red bed.
26. Woods Run limestone and fauna.
25. Saltsburg sandstone.
24. Portersville limetsone and fauna.
23. Upper Bakerstown coal (Maynadier coal in Maryland), Anderson coal in Ohio.
22. Albright limestone.
21. Cambridge red bed.
20. Cambridge limestone and fauna. Friendsville shale and fauna in Maryland.
19. Thomas sandstone.
18. Lower Bakerstown coal—Thomas coal in Maryland, Wilgus coal in Ohio.
17. Thomas limestone.
16. Meyersdale red bed.
15. Buffalo sandstone.
14. Brush Creek rider coal.
13. Brush Creek red bed.
12. Brush Creek limestone and fauna.
11. Brush Creek coal.
10. Irondale limestone.
9. Corinth sandstone in Maryland.
8. Gallitzin coal—Mahoning coal in Ohio.
7. Thornton clay.
6. Mahoning red bed, upper and lower benches.
5. Mahoning limestone.
4. Piedmont coal.
3. Mahoning sandstone.
2. Upper Freeport rider coal.
1. Upper Freeport coal.

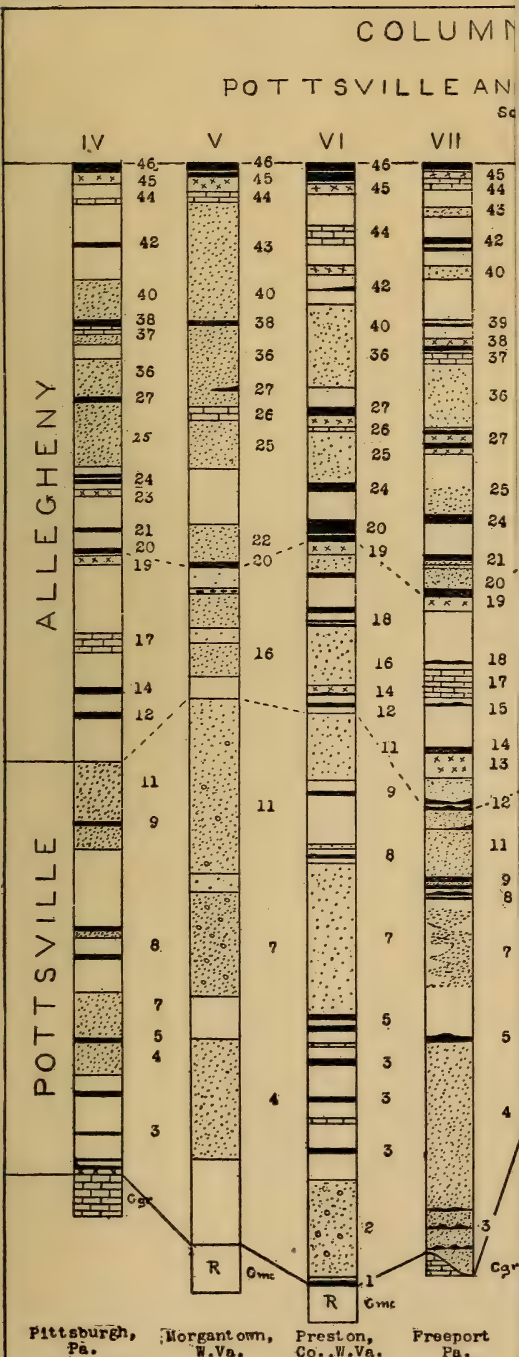
NOTE.—The correlation of the upper members is tentative. Their lenticular and variable character forbids confident correlation by data now available.

PLATE 15.—*Sections of Allegheny and Pottsville Formations*

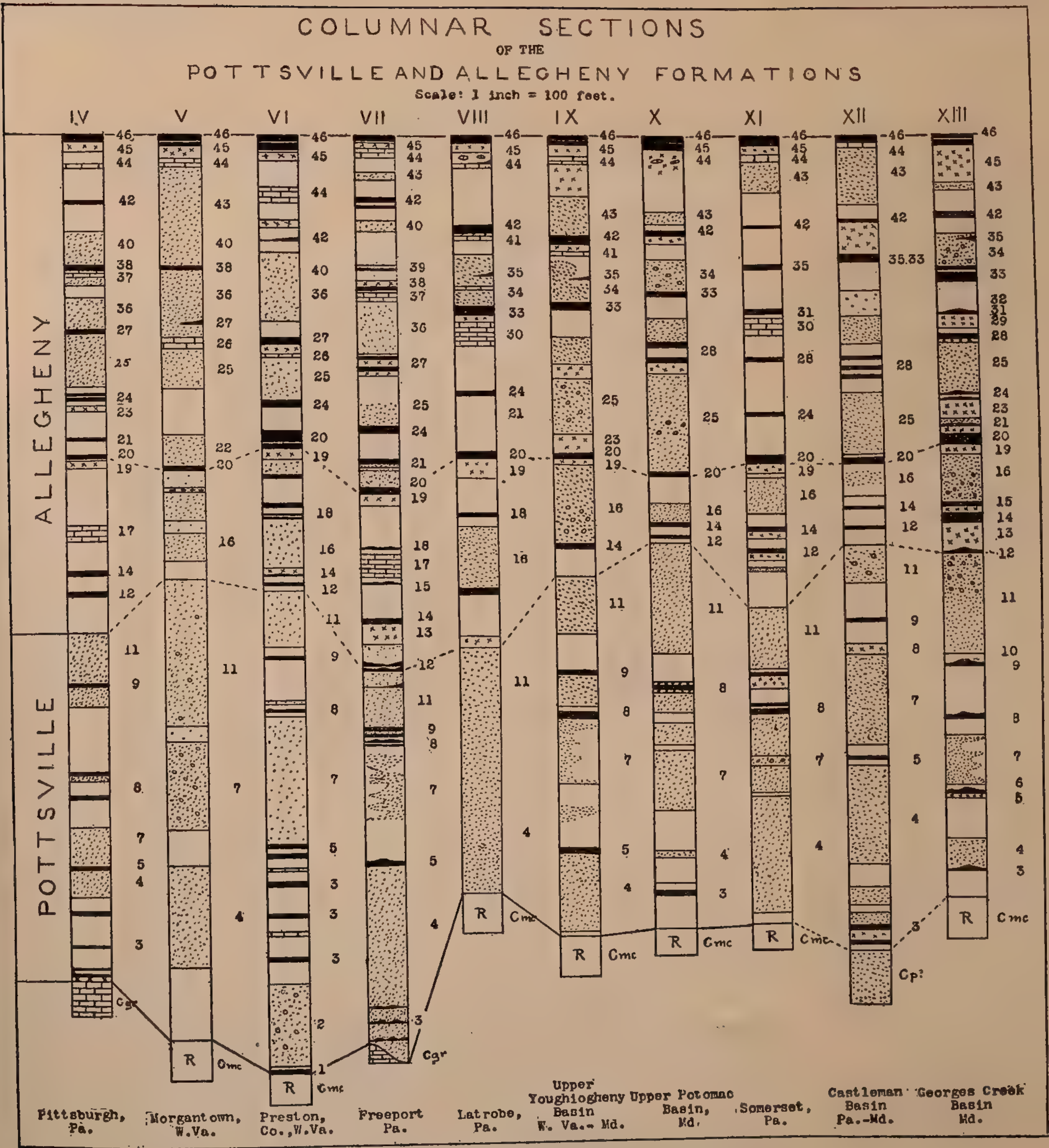
Numbers indicate members. Different numbers are assigned to the coals called the Upper Kittanning in the eastern and western sctions; * indicates fauna; Cmc—Mauch Chunk; Cp—Pocono; Cgr—Greenbrier.

46. Upper Freeport coal.
45. Bolivar fireclay.
44. Upper Freeport limestone.
43. Upper Freeport sandstone.
42. Middle Freeport coal. "Lower Freeport coal," Barrelville coal in Maryland.
41. Middle Freeport limestone.
40. Middle Freeport sandstone.
39. Lower Freeport rider coal.
38. Lower Freeport coal.
37. Lower Freeport limestone.
36. (Lower) Freeport sandstone.
35. Montell rider coal.
34. Montell sandstone.
33. Upper Kittanning coal east of Freeport.
32. Little Montell coal.
31. Johnstown iron ore—Mount Savage iron ore in Maryland.
30. Johnstown limestone.
29. Hardman fireclay, "Furnace clay" in Maryland.
28. Piney Mountain coal.
27. Upper Kittanning coal at Freeport and westward.
26. Upper Kittanning limestone.
25. Westernport sandstone.
24. Middle Kittanning coal.
23. Middle Kattanning fireclay.
22. Ellerslie sandstone.
21. Lower Kattanning rider coal.
20. Lower Kittanning coal.
19. Lower Kittanning fireclay.
18. "Ferriferous" coal.
17. Vanport limestone.
16. Mount Savage sandstone.
15. Scrubgrass coal.
14. Clarion coal—Upper Mount Savage coal in Maryland.
13. Clarion fireclay—Mount Savage fireclay in Maryland.
12. Brookville coal—Lower Mount Savage coal in Maryland.
11. Homewood sandstone.
10. Upper Mercer shale and fauna.
9. Upper Mercer coal.
8. Lower Mercer coal.
7. Upper Connoquenessing sandstone
6. Quakertown shale and fauna.
5. Quakertown coal.
4. Lower Connoquenessing sandstone.
3. Sharon coal.
2. Sharon sandstone.
1. Coal.

NOTE.—The members of the Pottsville, in the sections described, are subject to much variation. The correlation indicated is tentative.



SECTIONS OF ALLE



SECTIONS OF ALLEGHENY AND POTTSVILLE FORMATIONS

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POST-GLACIAL UPLIFT OF SOUTHERN NEW ENGLAND[1]

BY HERMAN L. FAIRCHILD

(Presented by title before the Society December 27, 1918)

CONTENTS

[1] Manuscript received by the Secretary of the Society May 24, 1919.
Entered as "Post-Glacial Uplift of the New England Coastal Region" in the printed program.

Introduction

In the early days of earth science in America, about the middle of the last century, the fact of recent oceanic submergence of northeastern America was recognized. The literature of the time, in particular the Proceedings of the Boston Society of Natural History, record many observations and opinions of the geologists of the day. E. Desor and H. D. Rogers were prominent, and the facts indicating submergence were used by Rogers to support the diluvial theory of the drift. Two quotations are pertinent.

"Rogers replied that he considered these remains evidence of the former existence of an extensive strait which cut off New England from the main continent" (volume 3, page 116).

"Mr. Desor had thus been led to the opinion that the sea had once filled the Saint Lawrence, Lake Ontario, and Lake Champlain" (volume 3, page 358).

The low attitude of New England at the close of the ice period appears to have been accepted down to the end of the century. The belief found extreme expression in the writings of Professor Shaler, who claimed 300 feet submergence below present level for Nantucket and Marthas Vineyard and 1,300 feet for Mount Desert Island. From this excessive estimate there was reaction. The intensive study of the morainal drift on the New England coast and Long Island led the later students to postulate a complicated Pleistocene history, and to refer the evident oscillations of the land level back in time to an epoch antedating the last ice-sheet. This concentration of study on the local glacial features appears to have diverted attention from the wider relations of the phenomena, and to have caused neglect of the positive evidence of Post-Glacial submergence in all the adjacent territory. Some of the writers on New England Pleistocene have asserted that during the removal of the last ice-sheet the coast stood as high, or even higher, than it does today. To explain the high-level sands with marine fossils, they allow submergence previous to the last ice-invasion, which appears discordant with the fact that abundant water-laid deposits are superficial over all the coastal region. The wide-spread evidence of high-level static water deposits in the inland territory was attributed to glacial, or ice-impounded, waters; for which barriers were assumed, but without any direct evidence.

In recent papers (numbers 74-81 of the accompanying bibliographic list) the writer has presented evidence of Post-Glacial submergence of the wide area that was covered by the last, or Labradorian, glacier. The classic ground of eastern Massachusetts and Rhode Island was not exam-

ined until the summer of 1918, after the facts had been acquired in the wider surrounding territory.[2]

The various proofs of Post-Glacial land uplift are clear. This conclusion runs contrary to the views in much of the later literature, and the writer's sense of duty to the truth is his apology for invading this well trodden ground and for venturing to disagree with many friends among the later writers on the New England Pleistocene.

The recent paper (1917), by F. J. Katz and Arthur Keith, on the Newington moraine in Maine, New Hampshire, and Massachusetts, confirms the fact of late submergence. They clearly state that the last deposits of the region overlie or overlap the moraine, and that "the region was submerged during the building of the moraine, and the ice-front was in the sea" (82, page 29).

The lower attitude of New England was also recognized and clearly stated by M. L. Fuller in 1898 (63, pages 312, 320).

Theoretic Discussion; Criteria

CHARACTER OF DEPOSITS

The complex of ice-laid and water-laid deposits in the terminal moraines of Long Island and Massachusetts have been interpreted as the record of multiple glaciation.[3] However, the evidences of and argument for Post-Glacial submergence described in this paper are not dependent on any theory of events during the time covered by glaciation, whether one, or two, or several ice epochs. The deposits and phenomena used in the present study are wholly surficial and postdate the last ice-occupation of the region, and are consequently independent of any up-and-down movements previous to the last ice-invasion.

The episode in the geologic history which is here described is that of the final removal of the glacier, and the problem is to determine if the surficial features agree with the theoretic conditions of (1) deep water facing the retiring ice-front; or (2) shallow proglacial waters; or (3) subaerial land surface beyond the ice-margin.

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[2] The writer makes grateful acknowledgment of financial aid from the Research Fund of the American Association for the Advancement of Science.

[3] The writer is not prepared to confidently discuss the Pleistocene history as it is recorded in the morainal belts, nor to controvert the published conclusions; but study of the later, or retreatal, moraines shows that much complexity of the deposits may result from merely the oscillations of the margin of one ice-sheet. It is possible that the glacial history of New England has been made too complex, and that future study will simplify the story. It is improbable that the Pleistocene history of New England is as complicated as that of the Mississippi Valley.

(1) Under the conception of open water laving the waning glacier and too deep for effective wave-work, the theoretic succession and characters of the deposits would be somewhat as follows: The foundation for the water-laid deposits might be either rock or till. The till might be differentiated, but if the marginal ice were thin and not too heavily loaded with drift, it might be floated away, leaving only the subglacial till, or perhaps none at all. The massive clay in the Hudson Valley often rests on glaciated rock. In the lake area of southeastern Massachusetts it appears that detached ice blocks were anchored and more or less buried in sand and gravel, producing a multitude of kettles.

The earliest (lowest) water-laid deposit from the glacial outwash would vary from cobble to sand and would commonly include much coarse material. If the detritus were poured into deep water, it would receive little assorting and would produce unstratified or pell-mell structure. The finer suspended matter would generally be swept away, leaving the deposits without silt, although in sheltered localities some silt might rarely be added to the primary deposit. As the ice-front receded the suspended silt would be floated out and precipitated over the earlier, coarse, pell-mell deposits. Locally, in case of very vigorous stream outwash, effective current might carry sand some distance seaward and spread it with partial stratification; but streams from the glacier into deep, wide water would commonly be too quickly checked to produce stratification.

When the ice-front was far removed, only the finest, suspended silt could reach the deserted area, and the coarse, pell-mell deposits might receive a topping of clay.

Out of the possible variation in the deep-water deposits there remains the broad fact of coarse detritus at the base with prevailing pell-mell structure, and silt at the surface over the greater area of submergence.

It appears that the rise of land was *nil* during the removal of the ice-sheet from the area, or at least so small in the coastal region as to be negligible.

The next phase in the theoretic history involves the rise of the unweighted land and the shallowing of the waters, implying seaward extension of the dry land and lengthening of the rivers. The clays from the glacial drainage might shade into the silts and clay from the subsequent river contribution. Within the range of river currents the clays might eventually suffer erosion, by river work or tidal scour, and over the irregular surface sand or gravel might finally be spread, as the latest work of the shallowing waters. Sharp unconformity between clay beneath

and gravel above is seen in the Hudson Valley, but such structure might be more readily produced in a valley with lateral inflow than in the open sea. It is possible that unconformities of similar origin might be interpreted as evidence of multitple glaciation.

Within the range of vigorous rivers the earlier marine deposits would be more or less buried under the shallow water and stream detritus, the latter grading upward from fine to coarse, in this respect being the reverse of the deep-water deposits. Over wide areas unaffected by rivers or by tidal scour the deep-water silts and clays would be lifted into the air as the surface material, as in the lowlands of the Boston district.

The complete ideal succession of the deposits initiated in deep water may rarely be exposed, but two elements are common, namely, the pell-mell gravels and the superficial clays, especially in eastern and southeastern Massachusetts, where the oceanic waters were deepest.

When the ice-front had receded to higher ground, so as to be faced by shallow water, the glacial outwash would build sandplains, the deltas of the glacial streams; and when the ice-front had backed away entirely from the sea and lay on the exposed land, all the streams, of glacial or of land drainage, would build deltas in the standing water. Such deltas were inevitable, and they mark the highest stand of the sea or lowest of the land at the time of the ice removal in any district. These summit-level deltas are the heaviest deltas of the streams, for the reason that each stream then had its greatest burden of detritus, the glacial outwash being added to the land drainage, and the latter then having its heaviest load, derived from the newly exposed, drift-covered land surface.

Subsequently, during the slow rise of the land, the reduced load of the streams, and this of finer material, was distributed along their courses in the sealevel waters, being commonly spread about as filling of low areas instead of forming distinct deltas. The summit-level delta, the record of the deepest submergence, is practically the only heavy, well marked gravel plain in each river valley. These early gravel plains are the most inevitable and the most reliable features for determining the approximate amount of land uplift since the ice-sheet deserted the district.

With the rise of the land and the shallowing of the sea the zone of effective wave action was slowly lowered over all the inferior land surface. The localized glacial deposits of gravel (kames), consisting of coarse and well rounded stuff, and therefore sensitive to wave impulse, were more or less leveled, truncated, or planed. The Newtonville sandplain is an example of a partially leveled kame area. In eastern Massachu-

setts these plains of erosion have been wrongly attributed to glacial lake waters.

Without long pauses in the land uplifting, or a stand-still of the waters, erosion features such as sea-cliffs, or constructional features such as spits and bars, would not be formed (77, page 299; 81, page 199).

(2) Under the conception of shallow waters laving the receding ice-front, so shallow that stream-flow and offshore currents were effective, the unassorted or pell-mell gravels that are characteristic of deep-water genesis would be absent and would be represented by plains of stratified materials sloping seaward. Such submarine plains should exhibit very smooth surfaces, and the materials should grade, horizontally, from coarse to fine as the offshore depth increased. In line with the entrance of streams of glacial outwash, shallow scourways would exist, and as they concentrated the tidal ebb and scour, they might persist and extend seaward, as the land rose, perhaps even without the aid of stream currents. The smooth plains of Long Island, Marthas Vineyard, and Nantucket are considered good examples of submarine plains in shallow water.

The final rise of the land would leave the surfaces that had fallen within the range of detritus with deposits more or less differentiated, as noted above. Pell-mell structures and smoothed kame areas would be wanting. When land streams came into existence their work would be mostly erosional in the belt of the shallow-water deposits. In this connection it becomes important to discriminate the constructional, or outwash, plains from the erosional, or wave-leveled, plains (see page 609).

(3) Detrital plains built above the sea, or other standing water, of subaerial construction should possess some characters that would distinguish them from subaqueous plains. Such discriminative characters have not been recognized, for the plains of Long Island and Nantucket have been referred to both classes of deposits. Geologists who deny the recent submergence of the coastal region regard these plains as subaërial glacial outwash. The very level surfaces are supposed to be produced by the blending of alluvial cones by lateral migration of loaded streams, or as the aggraded upper, subaërial portions of vast united deltas. A brief discussion of these plains may suggest some criteria.

The plains lack the anastomosing channels of "braided" rivers on aggrading deltas, and the dividing or distributary channels of either fans or deltas. On the contrary, the "creases," or so-called channels, unite seaward, widening and becoming undefined. They do not hold coarse detritus, as rounded boulders and cobble, which should be the case if formed by land streams, but, especially on the lower ground, are

floored by sands and silts similar to the materials forming the plains. The creases do not have the definite form and character of land streams, but agree with the supposed form and nature of tidal scourways. Along lines parallel to the sea the plains are very flat and smooth, except for the intercepting creases, and are too smooth for the conception of a series of united fans. The slope seaward is too steady, and with too low gradient to represent subaerial gravels. The composition of the plains is too uniform, and on the low ground too fine, to be the deposition of land streams from glacial outwash. Further description of these plains is given in writings 27 and 77. If they were the product of subaerial glacial outwash, then similar plains should have been formed on uplands, in unconfined areas, along the face of the retreatal moraines.

GENERAL STATEMENT

The third postulate, as given above, must be ruled out, admittedly for the mainland. The wide silt and clay plains of the low grounds are recognized as products of deep water. The great number of kettles and kettle lakes in southeastern Massachusetts among level plains of sand and silt can not be explained by mechanics of subaerial agency.

The suggestion that the morainal belt and border of the mainland received its uplift previous to the last ice-invasion has no support in fact. Over all the area the phenomena of standing water are superficial and unaffected. There is no evidence of any glaciation of New England subsequent to that which built the great terminal moraine. Any late ice-sheet would have more or less obliterated the features made by the submergence and should have left a distinct terminal moraine and other conspicuous evidence.

The second postulate, that of shallow waters facing the receding ice-front, is also disproved. The heavy deltas and extensive cobble plains that must mark the edge of the standing water are absent on the low ground, where we find the clays and other proof of deep water. The Merrimac River will serve as an illustration. If the area of eastern Massachusetts had stood near its present level at the time when the ice-sheet melted, the river would have built a huge gravel delta in the district of Newburyport, and its aggraded coarse deposits would have buried all the low ground along its course in Massachusetts; but its earliest, heaviest, and coarse deposits were dropped far north in New Hampshire. Over the lower ground, in Middlesex and Essex, it spread only finer detritus, contributing to the low marine filling among the hills about Lowell and Lawrence and the wide plains about Newburyport.

As all of eastern Massachusetts carries abundant evidence of standing water, the question of the genesis of the phenomena on the higher ground lies between glacial lake waters and marine submergence. The suggestion of an ice-dam lingering on the east and south while the larger area was relieved of the glacier is at least unreasonable. The existence of partial or local ice-barriers on the seaward side for some low areas does not meet the demands, because static water phenomena occur abundantly over all the territory of New England that lies beneath the imaginary surface joining the isobases of the maps (figures 1 and 2). These phenomena are described in later chapters.

If no measurable rise of land occurred previous to the removal of the glacier from the coastal region, it follows that any glacial outwash plains marking a water surface must record the highest water level. Kames and moraine could be dropped in the deep water, but no plains could be built in deep water in contact with the ice-front. Glacial outwash plains were built only on higher ground or in shallow water and only at the summit marine level. The earliest river deltas also mark the early water level. Consequently, near the limit of glaciation any true glacial plains and any heavy stream deltas of coarse materials are positive record of the deepest Post-Glacial submergence.

If any rise of land did occur while the ice-sheet lay on the area or before the plains were built, which is possible for the inland area, then the submergence and subsequent uplift is greater than the present height of the plains above the sea.

Wherever the ocean lapped the land when the Labradorian ice-sheet was melting, either outwash plains or stream deltas were built along the sea margin. These bedded deposits are the inevitable and conspicuous proof of standing water and of the highest stand of that water. Such summit deltas are found on practically every stream course, and with such accordant levels that prediction can confidently be made; and prediction has been successfully made many times. The summit deltas of Massachusetts and Rhode Island will be noted below.

The hills of gravel (kames) built by concentrated glacial drainage in submergence and then brought to the sea surface by the land uplift were more or less worn down and leveled by wave and current work. The great number of sandplains on low ground are of this nature. The Newtonville plain (53) is a good example of leveled and truncated kames. The knolls were built in deep water and the leveling took place subsequently in very shallow water. The plain is not a constructional glacial plain, but an erosional marine plain. One or more points of

knolls stand above the plain, as evidence of the failure of the waves to complete their work. Other plains in the immediate neighborhood have different levels. The list of 30 plains or leveled tracts given by Clapp (68, page 202) emphasizes the fact of great discordance in altitude of plains in the same district. That they were not laid in glacial lake water is proven by the following negative characters: No relation to any lines of land drainage; no relation to any passes across divides; no correspondence in altitude; no similarity in form; no definite structures. They are wave-smoothed kame or other deposits which were sensitive to the agitated oceanic waters (see further description, page 609).

As land uplift progressed and the rivers extended seaward, intrenching their earlier deltas, they swept detritus over the lower ground within their reach; but, as no heavy inferior deltas are found, it is concluded that the rise of the land was comparatively steady, and that the rivers spread their later loads, which were finer detritus than at the higher levels, mostly under the sealevel waters.

A criterion of the primitive water level is the unmodified form of the kames and moraines in areas above the theoretic marine surface and the washed down forms beneath that surface. A good locality is the morainal tract between Foxboro and Wrentham.

Submergence Phenomena

1. Summit Deltas

These deltas are not the stream-contributed deposits at inferior levels, but the plains built at the initial and summit level of the sea by the streams (rarely glacial outwash in this region) flowing from the higher, unsubmerged ground. These summit deltas, as valley filling, are represented on practically every stream examined in northeastern America lying within range of the theoretic submergence. They may be confidently predicted for every stream.

Deltas produced during a single phase must have similar altitude; but deltas built far inland, in the deep valleys, might be laid after some rise of the land had occurred, and hence such deltas do not register the full amount of land uplift. In the area under present discussion any variation of this kind must be very small, if present at all, and certainly is negligible.

Heavy deltas built in constricted valleys by vigorous and well loaded streams might displace the estuary waters for some miles, so that the line of standing water becomes far distant and much below the head of

the aggraded delta. This difficulty will not often occur in the area described.

With the lack of the two elements above noted, there may yet be some variation of the delta surface from the theoretic marine plane, due to differences in the construction of the deposit, whether above or beneath the water surface, and to the various sources of possible error, already noted.

Deltas laid in narrow and steep-walled valleys are subject to great erosion and possible obliteration of the critical plane; but this is not likely to occur in our area.

Following is a tabulation of a few of the observed summit deltas on the larger streams. Some description of them is given in the later chapter on areal description.

No examination has been made of the many small streams and wet-weather runs pouring southward from the uplands into the high-level waters. These will surely record the summit marine level, and with greater precision than the aggraded deltas of the larger rivers. If the topographic maps had the accuracy and "expression" of the latest sheets, the location of many summit deltas could be fairly predicted. An example is found on the Kent sheet, southeast corner, where the contour lines suggest marine summit planes at about 220 to 200 feet.

Deltas recording the Summit Marine Level

River.	Locality.	Topographic sheet.	Elevation (feet).	Marine summit (feet).
	Massachusetts			
Millers	Millers Falls	Warwick-Greenfield.	360–375	385
North Nashua ...	Fitchburg	Fitchburg	390–400	395
Monoosnoc	Leominster	Fitchburg	380	385
Blackstone	Saundersville	Blackstone	320–330	325
West	Northwest of West Upton	Blackstone	300–330	320
Mill	West of Milford....	Blackstone	300–320	320
Nashua	Clinton	Marlboro	340–380	375
	Connecticut			
Five-Mile	Danielson-Dayville .	Putnam	240–260	265
Quinebaug	Putnam	Putnam	280	285
Moosup	Moosup	Moosup	240	255
Nachaug	Willimantic	Norwick	250–255	255
Willimantic, Hop.	Willimantic	Norwich-Gilead .	260	260
Hockanum	Rockville	Tolland	260–270	275
Paquabuck	Bristol	Meriden	240	240
Quinnipiac	Plainville	Meriden	240	240

2. *SUMMIT-LEVEL SANDPLAINS*

Several wave-planed areas of gravel or sand are found at, or very near, the marine summit level. These have no relation to any existing rivers and the deposits are evidently glacial; but the waters which gave the level surfaces were not glacial, as they all lie either in or facing seaward drainage. The plains at Sharon and Foxboro stand on the main divide between northward and seaward drainage. The extensive plains of Long Island and Nantucket are regarded as examples at the glacier terminus. The following tabulation gives a few examples seen by the writer. Doubtless other examples will be found. Some description is given later.

Locality.	Topographic sheet	Elevation.	Marine summit.
Massachusetts			
Sharon Heights	Dedham	280–285	295
Foxboro	Dedham-Franklin	280–290	290
Gay Head (smoothing)	Gay Head	130–135	155
Nantucket Island	Nantucket	40– 80	80
Rhode Island			
"Dugaway Hill," southwest of Providence.	Providence	240	255
Woonsocket	Burrillsville	280–290	290
Connecticut			
"Mile Plain," northwest of New London.	New London	160–180	200

3. *WATER-LAID DEPOSITS FACING THE SEA*

A few surficial and bedded deposits of standing-water origin lie at high levels close to the open sea. No one has ventured to attribute them to glacial waters, but they have been credited to submergence previous to the last ice-sheet; yet they overlie the morainal drift and are the latest phenomena of the districts.

Locality.	Topographic sheet.	Elevation.	Marine summit.
Gay Head, Marthas Vineyard	Gay Head	120–125	155
Sankaty Head, Nantucket	Nantucket	80	80
Manomet Hill, east of Plymouth	Plymouth	230	235
Highland Light, North Truro	Provincetown	120	190
Mount Desert, Maine	Mount Desert	230	250

The brilliant clays at Gay Head are capped by Pleistocene sands. The wave-smoothed plateau on which stands the lighthouse, restaurant, and wireless station has an altitude by the map of 130 to 135 feet. By the map of isobases the marine summit is about 155 feet and overtops the highest knoll. The higher hills of the island exhibit effects of wave-action, but the moraine is so stony that the limit of wave-work is not clear.

In discussion of a paper by David White (35), F. J. H. Merrill said:

> "The opinion of the writer, that the Gay Head strata were Post-Pliocene, was chiefly based on the evidence of a stratum of Post-Pliocene sand, which is the uppermost member throughout the section, being repeated frequently by faults, and at one point containing fragments of *Venus mercenaria* and other Quaternary shells" (37, page 556).

In 1892 P. R. Uhler also made record of the surficial sands (43, pages 176-177).

At Sankatay Head, east end of Nantucket, the bedded sands carry fossils to at least 50 feet above tide. Papers 3, 4, 16, 17, 18, 31, 38, and 48 refer to this occurrence. In paper 38, pages 10-16, Merrill said that he measured the stratified sand to 83 feet above sealevel.

Another critical locality is the north end of Manomet Hill, some five miles southeast of Plymouth. This hill is crossed by the road to Manomet village at about a mile from the sea. The altitude of the road summit is 240 to 250 feet. Up to about 230 feet the evidence of standing water is conspicuous and abundant, in horizontal sands and gravel. On the west side of the hill a broad gravel plain lies at about 230 feet. On the east slope water-laid deposits are well exposed in the new road cutting at 230 feet, where the surface deposit is 3 to 5 feet of fine sand, inclosing numerous boulders, evidently the product of ice-rafting.

The stratified sands by the Highland Light, North Truro, on Cape Cod, are well known. The altitude of the top of the cliff of bedded sand is about 120 feet, but the wave-smoothed plain on which the lighthouse stands is 140 feet. Looking southward, the work of standing water is apparent in the perfect horizontality of the land surfaces and the sky-line. The theoretic uplift here is 185 to 190 feet, which gives 45 to 50 feet of submergence. The presence of huge boulders in the gravels, seen by the road near the Highland House, one being 10 feet in diameter, is evidence of sufficient depth of water to permit the rafting of heavy boulders. There is no suggestion here of surficial drift. Standing water was positively the last occupant of the region.

In his paper on changes of level at Cape Ann, Massachusetts (71),

R. S. Tarr described gravel bars 40 to 60 feet above the sea. In the supplementary note Woodworth raised the figures to 80 feet. Tarr also described and figured contorted sand beds at Gloucester containing marine fossils and large boulders, and says:

"The clayey layers also suggest a subsidence sufficient to remove the area from the immediate neighborhood of the rocky coast; and the presence of boulders, some of which are fully two tons in weight, suggest sufficient depth for large masses of ice to float. It seems difficult to account for these transported fragments in water having a depth less than a hundred feet" (71, page 191).

Our map, figure 2, makes the submergence at Cape Ann about 350 feet. The disturbance of the sands might be due to icebergs, and the overlying till is probably berg till.

4. SANDPLAINS OF INFERIOR LEVELS

Wave-smoothed and more or less leveled plains occur at all levels, from the summit marine plain down to the present sealevel, and they are regarded as the proof of the slow rise of the land out of its submergence. These plains are not limited to valleys or hollows or embayments of the land, and glacial waters are too ephemeral and too spasmodic to produce such vertical series of plains. The Newtonville sandplain and the many smoothed tracts in the same district, noted by Clapp (68), are examples of this class of abundant features (see page 604).

For reasons given above, it is believed that the inferior plains could not have been built as outwash plains in contact with the ice-front and at the water level, although when deposited as kame or pell-mell gravels in deep water the deposits were commonly banked against the ice-front. Some of the form due to the ice contact may be preserved during the later process of wave-leveling. As these level sand areas have been interpreted as outwash plains at water level, or glacial deltas, it is desirable to note some of the discriminating criteria.

True constructional plains should exhibit delta form and structure, as clearly set forth by Davis in 1890 (40). By contrast, the wave-leveled or erosional plains, due to smoothing of kames or deep-water deposits, should lack most of the delta characters. They should be more nearly level, and any surface slope should decline away from the side of wind exposure and heavy wave-work, and would commonly be in opposite direction from the glacial outflow; or, the declining slope may be radial from the original knolls or locus of supply. The gradation in size of the surface materials should tend to have the same relationship

as the surface slope. The ice contact of the original construction may not be wholly destroyed, or the kettles and irregularities of the deposit may partly persist, especially on protected sides, as in the case of the Newtonville plain. The drifting of the wave-swept material might pile slanting beds at the margin of the plain, which could perhaps be mistaken for foreset or backset delta structure. Sometimes remnants of the original masses might remain, like the knolls in the Newtonville plain.

Equivocal structures and misinterpretation of the plains is more likely in the case of the coarser deposits and at the higher levels. The great number of fine sand or silt plains on the low ground of Massachusetts and Rhode Island could not be regarded as constructional at water level.

The conspicuous evidences of wave-leveling are so common over most of the submerged territory that it seems almost superfluous to present any list of localities. However, the following are a few examples that have been noted, omitting the list given in Clapp's paper (68):

Conspicuous Plains of inferior Levels

Locality.	Topographic sheet.	Elevation.	Marine summit.
Massachusetts			
Newtonville	Boston	140–200	340
Great Blue Hill	Dedham	200	315
Mansfield	Dedham	180	285
Wrentham	Franklin	240	300
Franklin	Franklin	280	300
Plymouth district	Plymouth	100–120	240
Barnstable, two miles south	Barnstable	80	170
Truro	Wellfleet	100–120	180
North Truro	Provincetown	100–140	190
North Tisbury	Marthas Vineyard	40– 60	155
Vineyard Haven	Marthas Vineyard	100	160
Connecticut			
New London and northward	New London	90–160	200–225
Norwich	Norwich	100	225
Bozrah Street (?)	Norwich	200	225
Plainfield	Moosup	200	250
Plainville	Meriden	200	240
Southington-Plantsville	Meriden	200	225
Rhode Island			
Providence district	Providence	40–200	260

5. *HORIZONTAL LINES*

Closely related to the inferior plains are the clean-cut horizontal lines which can relate only to fluidity. They occur at all altitudes up to the

initial marine level, but are, naturally, more evident in areas of abundant detritus and at the lower levels. About Plymouth they are very striking, up to 120 feet. They are also conspicuous at Truro and North Truro up to the highest land surface, at 140 feet.

6. PELL-MELL GRAVELS

These deposits have already been discussed. They are accumulations of detritus from glacial drainage poured into water too deep to allow assorting and stratification, and are rather characteristic of the morainal belts. The sand and gravel, the fine and the coarse, are mingled closely, and the deposits are compact, lacking the loose and open structure common to gravels of other districts. These gravels are more abundant toward the glacial border, perhaps chiefly because of the greater depth of water, and were especially noted in southeastern Massachusetts and in Barnstable County.

Wave-work of the shallowing waters might sometimes spread a veneer of assorted stuff, and on marginal slopes the shifted gravel might resemble backset or foreset beds and help to give a resemblance to constructional outwash plains.

7. SUPERFICIAL CLAYS

The extensive deposits of clay, the surficial material over large areas in eastern Massachusetts, are of necessity recognized as the product of deep or quiet water. They are precisely the expected effect of far removal of the ice-front, in deep water, before any large rise of the sea-bottom. The age of these surface clays is the vital question.

Writers admit that the clays of the Boston Basin were deposited in deep water, open to the sea, and that their occurrence at the present elevation of 100 feet over tide may not represent, on account of erosion, the full original height (34, page 994). The water surface in which the clays were laid must have been 100 to 200 feet over the clays, judging from the map of isobases.

But the Pleistocene clays and the other records of submergence, as the Highland Light beds and the Sankaty fossiliferous sands, were thought to have been deposited and elevated previous to the last ice-invasion. Appeal is made to down-and-up movement of the land during the life of the supposed earlier ice-sheets, and to elevated attitude of the land during the last ice epoch. In other words, the land was low, with submergence and clay deposition, during the time of removal of the earlier ice-sheet, but was elevated while the last ice-sheet was imposed.

This argues for diastrophic movement, not merely independent of glaciation, but in direct opposition to the probable effect of loading and unloading.

If the clay plains of the coastal areas represent submergence previous to the latest glaciation, then certainly that closing ice-invasion did not override the lowlands of New England. It appears probable that the Pleistocene phenomena of the coastal region have been misinterpreted, with the effect of thus making the history too complex. If the Boston surface clays and sands are older than the last ice, then there is a local history which has not been translated and which is much out of agreement with that of the surrounding territory.

8. *TERMINAL MORAINE OUTWASH PLAINS*

We turn again (see page 602) to the remarkable sandplains fronting the terminal moraines on the islands. Of course, they are outwash plains, and in the opinion of the writer they bear every character that should be expected of plains accumulated under shallow water. The far stretches of perfect level and smoothness of surface, taken in connection with the composition, structure, and disposition of the deposits, seem impossible of formation by any sort of subaërial work. The uniformity of the lower portions of the plains is attributed to the wave-work while the surface was rising out of the sea. The absence of beaches is not a valid argument against submergence, because bars and cliffs are rarely produced on sand areas without a standstill of land and water (77, page 299).

Lines of horizontality are seen on the plains and are noted on the face of the wave-washed moraine of Nantucket up to about 60 feet elevation.

9. *SUBMERGENCE EFFECTS ON ROCKY HILLS*

In a district of rock hills and high relief, as about Boston, the evidences of standing water are inconspicuous and elusive. The relatively steady rise of the land out of the sea prevented the production of shore-line features; but the fact of standing waters is shown by the rinsed-off surface of the slopes; the silted hollows; the prevailing absence of ordinary talus and detrital cones, instead of which are seen horizontal lines where the wave-borne detritus was banked against steep and irregular slopes; and the absence of perched and insecure erratics on slopes exposed to effective waves.

The characters of the rock hills of the submerged area of Massachu-

setts are similar to those of the rocky areas of northern New York and Vermont that have been subjected to immersion (76, page 11).

10. ABSENCE OF FOSSILS

The absence of fossils from the higher horizons of the submerged territory is not sufficient argument against marine submergence. Marine fossils are rarely found in deposits laid close to the glacier margin. The physical conditions which appear to have inhibited life were: the mechanical effect of coarse and moving detritus, the muddiness of the water, the low temperature, the low and variable salinity, and the lack in the glacial outwash of organic matter required as food.

The Maps

The general map of isobases of Post-Glacial uplift, figure 1, is reproduced from the preceding paper (81), and the local map, figure 2, shows the isobases for southern New England in more detail and with some modification of the earlier map, the latter chiefly in a slight increase of the uplift.

The lines are generalized and regularly spaced, yet express the facts from field study in a surprising degree. It might be supposed that some irregular rise of the land, or crustal warping, would produce variation in the upcurved surface, expressed in irregularity in the isobases. It appears probable that most of the diastrophic movement in the land surface is due to compression and expansion of the earth's mass, and that such great depth is involved that differences in the surface lithology would have little or no effect. As the larger topographic features were very old, and isostatic equilibrium had long been established, the surface relief could have little effect, except as conditioning the depth of ice.

Future intensive study may relocate the isobases, with possible recognition of some slight irregularity. In the main the map expresses the large truth. It is based on wide field study, not only of the limited area, but of the surrounding territory.

Emphasis is not laid on great precision of the figures and no effort is made to give figures within multiples of five. There are various sources of errors, as inaccuracies in the old topographic maps; in the railroad elevations; uncertainty in the interpolation between the 20-feet contours; errors in the aneroid measurements; and possibly, though not probably, to irregular warping of the land surface. However, with du-

recognition of possible errors and in spite of them, the agreement of the field measurements with the generalized lines of the upraised surface is very close. Confidence in the general accuracy of the map and in the amount of the land uplift is based on the practical accordance of a multitude of phenomena over the whole area and the correlation with the neighboring territory.

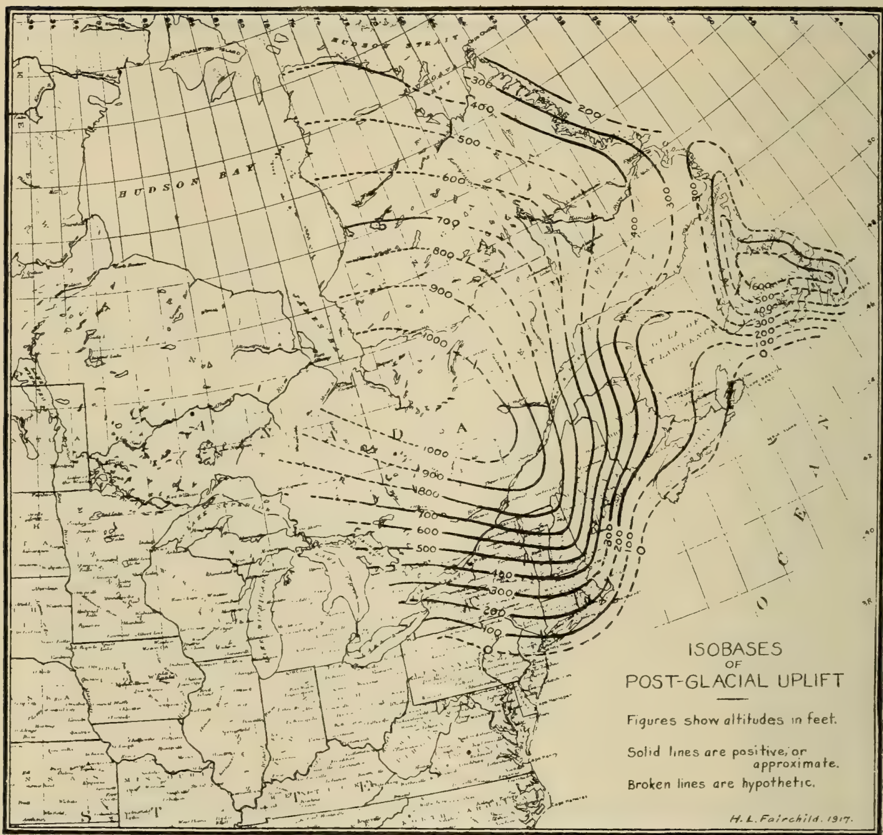

FIGURE 1.—*Post-Glacial Uplift of northeastern America*

The lines indicate, in feet, the amount of land uplift following the melting of the Quebec (Labrador) ice-sheet.

The map indicates, what theory seems to require, the more extended deployment or farther push of the glacier on the land areas (81, page 201), and shows a slight lobation to the southeast, over the islands and Cape Cod. It is possible that the lobation of the ice-sheet over this sector was greater than the map suggests.

Figure 3 shows in a generalized way the drowned areas at the maximum submergence; but the flooding here shown did not prevail at any one period of time. The progressive land uplift had probably raised some of the southeastern territory out of water while the ice-sheet was yet resting on the northern part of the area.

As most of the large area is hilly, and some with high relief and with many interlacing valleys, it is impossible in a sketch map to indicate the submergence with accuracy. In the widely flooded areas there are many hills which stood as islands. For the depth of submergence comparison should be made with the map of isobases, figure 2.

Areal Description

IN GENERAL

The submergence phenomena of a few districts deserve brief description, even if involving some repetition of facts already stated. One area not strictly covered by the title of the paper requires notice—that of Mount Desert, Maine.

CONNECTICUT VALLEY

Flooding.—This valley was flooded by estuarine waters to South Lunenburg, Vermont. The lower silt plains are a conspicuous topographic feature. The higher and more sandy stretches are less prominent, but evident as standing-water products when their nature and relationship are recognized. All streams pouring into the estuary built deltas at the highest level; and these, with some shore phenomena, record the full amount of the submergence. The heaviest gravel bars seen by the writer are at Portland, Connecticut, with altitude 220 feet, and at Bradford, Vermont, with altitude 660 feet.

In Massachusetts.—The Connecticut Valley is the only ground in the western part of the State which stood low enough to be immersed in the sealevel waters. The evidence of the high-level waters was shown and the deposits mapped by Professor Emerson long before the writer began this study of continental movement. The writer has examined a sufficient number of localities to prove the fact that on every stream which poured from higher ground into the valley estuary a delta was built at the summit marine plane.

Professor Emerson made the summit water plane 400 feet at the north line of the State and 288 feet at the south line. Recent study by the writer requires that these figures be raised about 10 feet.

A good example of stream delta built in the Connecticut estuary is found on Millers River, at Millers Falls, on the Warwick and Greenfield

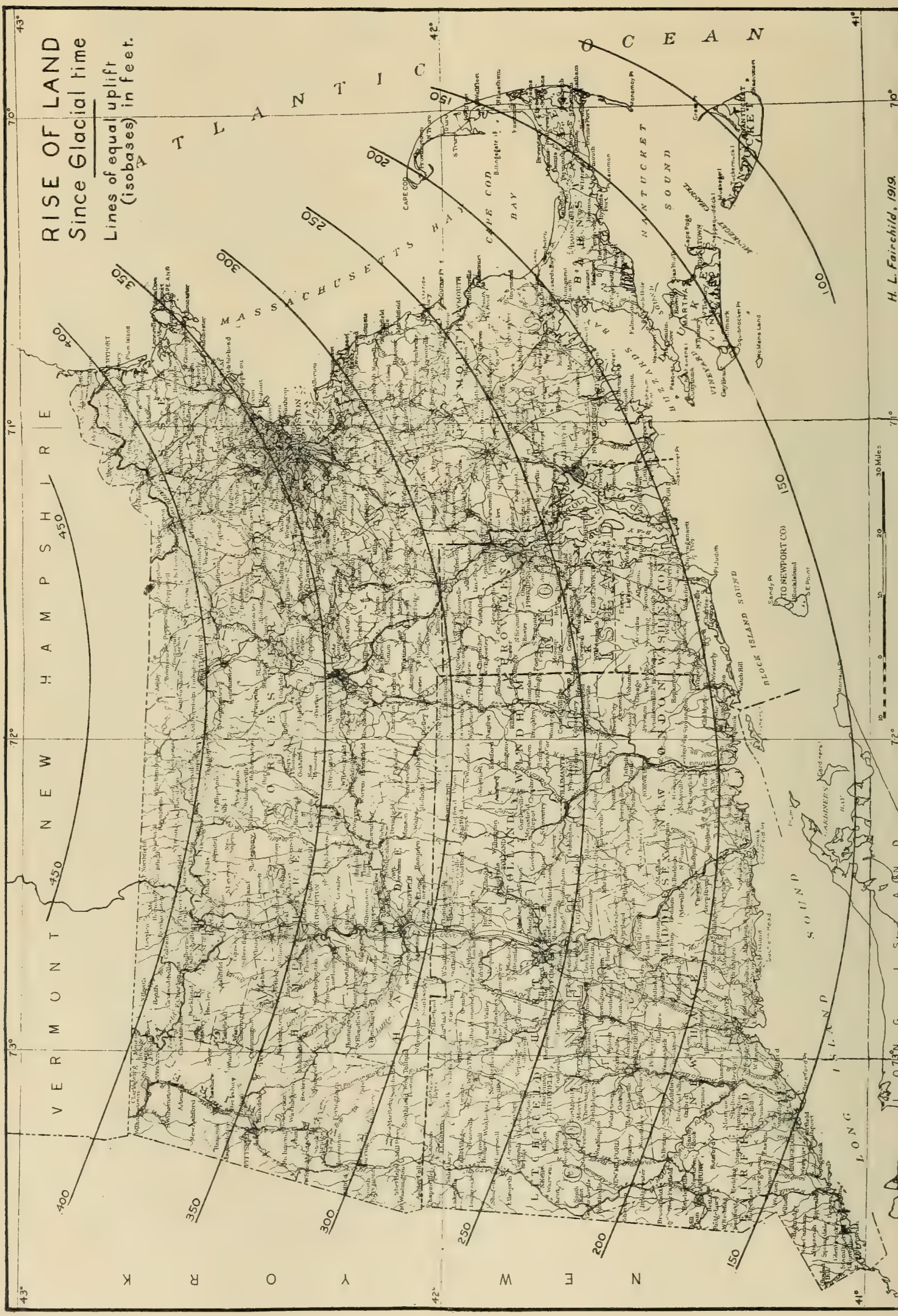

FIGURE 2.—*Isobases of Post-Glacial Land Uplift of southern New England*

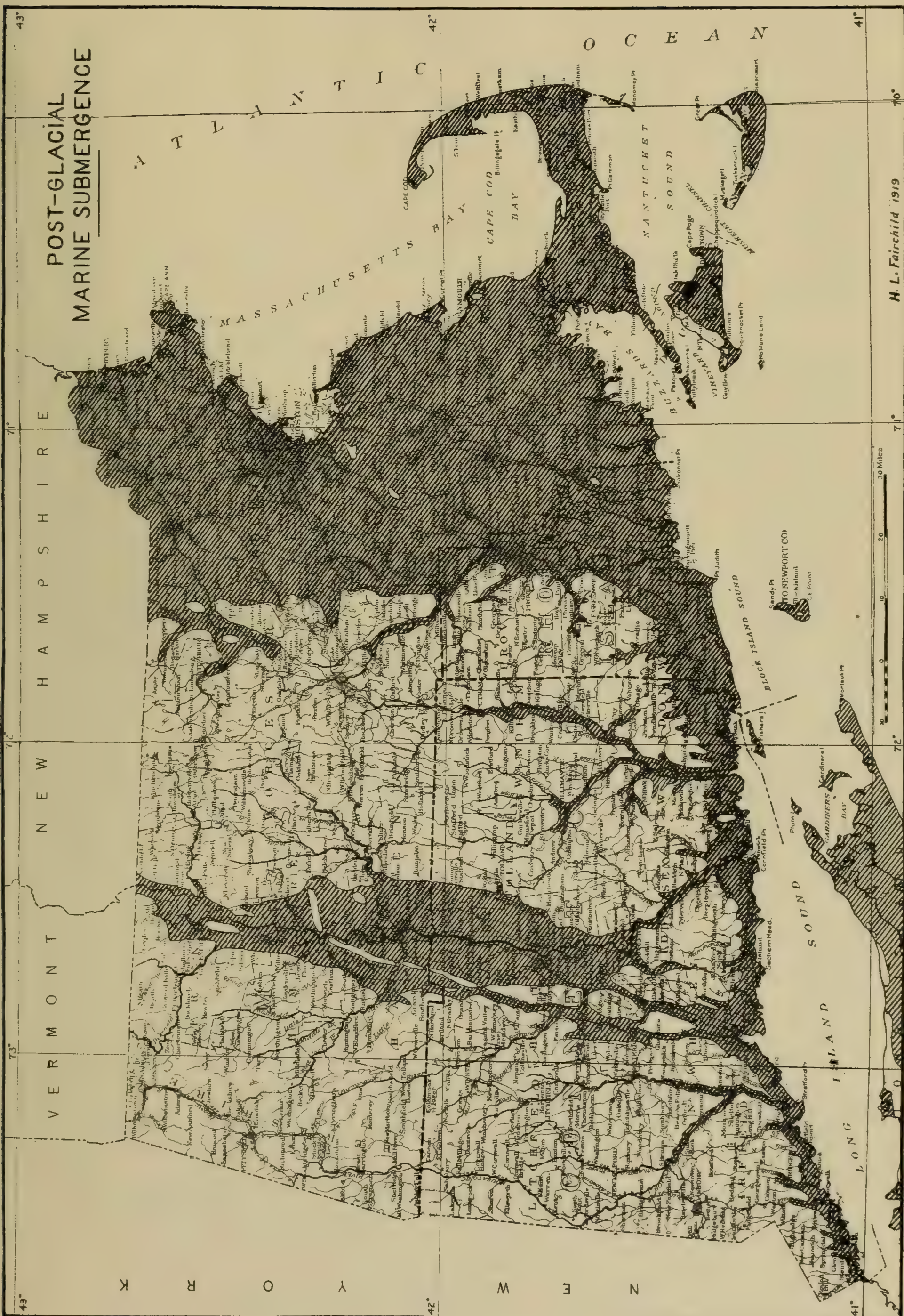

FIGURE 3.—*Post-Glacial marine Submergence of southern New England*

sheets. The village lies in the valley eroded out of the delta, which spreads mainly to the southwest, where it forms an extended gravel plain with elevation 340 to 350 feet. An area of kettles with sharp relief includes the Green and Great ponds. West of the village the delta has altitude by the map of 360 feet, with its back slope rising to 370 feet, above which is a kame area at over 400 feet. East of the village a distributary channel heads on the plain at about 365 feet and lies along the south side of the delta, against the rock wall. A remnant of the delta by the railroad station is 340 feet, using the Fitchburg Railroad as 290 feet.

Passing eastward up the valley of Millers River, remnants of the aggraded delta which once filled the narrow gorge are occasionally seen, rising to about 390 feet at Farley, where a good plain marks the delta head. Above Farley only glacial gravels are seen.

The estuary plains south of Millers Falls may be seen in Emerson's maps, and the standing water summit will closely agree with our map, figure 2.

In Connecticut.—No thorough examination has been made of the entire valley in Connecticut, but in addition to former observations two critical districts have been recently studied. One is the east wall of the valley in the Hartford district, shown in the Tolland sheet. The Hockanum River is the principal stream, and its delta is found at Rockville, with altitude about 270 feet, which is almost the height of the marine summit. The estuary shore is quite distinct.

The other district is the Farmington-Quinnipiac Valley. This interesting valley, which carries a middle stretch of the Farmington River and the lower Pequabuck and the upper Quinnipiac rivers, was flooded by a branch of the Connecticut estuary. The uplifted marine plane rises from 225 feet at Plantsville to 240 feet at Bristol and 250 feet at Farmington (Meriden sheet), but the floor of the valley has slight difference in level, and the singular northward turn of the Farmington River at Farmington and of the Pequabuck at Plainville requires explanation. The present divide between the Pequabuck, flowing north to the Farmington, and the Quinnipiac, flowing southward, is at Plainville, on a smooth gravel plain with altitude 180 feet. The Pre-Glacial drainage of all the valley was southward (see Manual of the Geology of Connecticut, Bulletin No. 6, Connecticut Geological Survey). The explanation of the present anomalous flow appears to be found in diversion by the delta filling built in the marine estuary. The sweep of the earlier river currents during the marine flood was southward, and the earliest and

heaviest load of detritus, especially that of the Farmington River, was drifted southward. The delta of the Pequabuck River in the highest water was built at the edge of the highland southeast of Bristol. This splendid delta, with altitude 240 feet, carriers the head of Eightmile River and the kettle which holds Lake Compounce. When the land rose and the Pequabuck extended its flow to Plainville the heaviest accumulation was yet southward in the restricted estuary, now at 180 to 200 feet. As the estuary waters gave place to rivers the Pequabuck River was obstructed by its own delta and was diverted northward, on the weaker side of the delta.[4] It should be noted that no heavy tributary joins the Farmington River north of the Pequabuck.

At and below the summit marine plane the evidences of standing water in the great valley are profuse. Many deltas of weak streams lie along the valley walls. A good locality is the flank of the Bristol highland the whole length of the Meriden quadrangle. Good delta terraces are suggested at Mixville and at Marion and northward to Compounce Pond; also at Polkville north of Bristol. The summit delta plain at Bristol is handsome. The smooth gravel plain abuts sharply against the Bristol hills; with clear limits. The improved road leading north from the mouth of the gorge is on the contact between rock and till on the west and the delta plain on the east. An important fact is that here the material of the delta is only sand, while south of the river it is gravel. The apex of the delta at the mouth of the river gorge is about 245 feet, according to the Meriden sheet. The broad plain east and south is 240 feet, which is taken as the summit marine level.

The singular ridge along the east side of Compounce Pond appears to be a strip of the delta deposited between ice blocks. The top shows similar height and slope as the adjacent delta plain.

FITCHBURG DISTRICT

Passing eastward from Millers Falls, by the Fitchburg Railroad, over the highlands, we drop to the marine level at Fitchburg. Here is the delta filling of Whitman River and Baker Brook. The altitude of the marine level is taken as about 400 feet (the threshold of the railroad station being 440.66 feet).

Abundant evidence of the standing water is seen east of the city, in the valley holding Baker Brook and in the broader valley southeast of the city. The Lundenburg State road will lead the observer across the

[4] A good example of similar diversion is that of the Iromohawk River on the Schenectady-Albany delta (78, page 12).

Baker Brook Valley, where the submerged plains of fine material are conspicuous at about 390 feet. Southeast of the city, toward South Fitchburg, the valley, some three-fourths mile wide, was entirely filled with gravel, the benches on the valley sides being 390 feet and over. The Saint Bernard Cemetery is on a rolling gravel plain at 412 to 415 feet, which is probably a remnant aggraded above the estuary level. On the Duck Mill road, just below the railroad, a bench of coarse gravel is excavated at 390 feet. Excellent plains lie along the Mack road parallel with the railroad. Bakers Pond lies in a broad, lower plain with height 370 to 380 feet. The summit of the gravel deposits is seen both north and south of Youngs road, east of the pond, with altitude up to 410 feet.

Four miles southeast of Fitchburg the city of Leominster is on the delta of Monoosnoc Brook at about 390 to 400 feet. Leaving the North Nashua River at North Leominster and passing east to Ayer, evidence of standing water is common at elevations below 390 feet, in smoothed surfaces and detrital plains. At higher levels are kames and glacial deposits. At Shirley are wide plains of inferior level, about 280 feet, and at Ayer at 240 to 260 feet. Much of the area of Camp Devens is rolling sandplain at 260 to 340 feet. The divide east of Ayer, between Nashua and Merrimac drainage, is only 260 feet.

UPPER NASHUA VALLEY, CLINTON DISTRICT

The upper part of the Nashua Valley, in the towns of Boylston, West Boylston, and Clinton, is the only valley in eastern Massachusetts with such northward direction and high altitude as to hold glacial lake waters. Crosby has well described the district and the glacial features (58).

With the ice barrier on the north and west, the early escape for the impounded water was by the channel one and one-fourth miles south of Boylston Center (on the west edge of the Marlboro sheet), which leads south to Quinsigamond-Blackstone drainage. The altitude of this pass is 440 feet, by the map, being about 80 feet over the theoretic marine level. The next lower pass is two miles south of Clinton village, leading east to the Assabet-Concord drainage, with map altitude of 350 feet. Crosby makes this pass, which he calls the "South Dike" outlet, 365 to 375 feet, which is as high as the marine plane at this point. Even with this height it would carry outflow, the escape of Crosby's Clinton stage of the Nashua glacial waters (58, page 318). The next lower pass is at Ayer, with altitude only 250 to 260 feet, and it was drowned under 140 feet of standing water.

The prominent sandplain two miles north of Boylston Center, with

altitude 400 feet, is the only conspicuous plain, which stands so much above the marine level as to be wholly credited to glacial waters.

The most extensive and interesting static-water deposits in the district are the wide plains about Clinton village. Crosby writes:

". . . the Clinton plains, which are unquestionably equal in interest to all the rest of the modified drift of the Nashua Valley" . . . (58, page 323).

The Clinton plains lie west, north, and east of the village. The cemetery on the west edge of the village is contoured at 360 feet, while the extensive plain farther west, traversed by the railroad and the Sterling road, is 380 feet on the south of the roads and 360 feet on the north. East of the village, toward Bolton Station, the railroad cuts another plain with height about 360 feet.

Apparently the whole width of the valley at Clinton was filled with detritus from 340 to 380 feet. The theoretic marine level is about 375 feet by the map of isobases. Possibly the higher deposits may be credited to Crosby's Clinton stage of the glacial waters before the South Dike outflow had cleared the pass; and possibly the marine plane is higher than indicated in the map. The inferior plains certainly represent sealevel waters, which entered the net of valleys from the south and southeast.

As the ice-front receded the oceanic waters took possession of the broad valley northward, toward Ayer, and as the land rose out of the water the smooth stretches of sand and silt were formed at inferior levels, producing the plains down (northward) the Nashua Valley toward Ayer and up the valley of the North Nashua toward Fitchburg. The villages of Lancaster, South Lancaster, and Lancaster Commons stand on wave-leveled tracts. The oceanic waters covered the region before any measurable uplift had occurred, as indicated by the full-height deltas at Fitchburg and northward in New Hampshire. The horizontal deposits at all altitudes below the plains at Clinton indicate long-lived and very slowly falling water (relative to the land) and could not be produced in any glacial lake waters.

BOSTON-WELLESLEY-ASHLAND DISTRICT

The steep hills of rock and the coarse drift about Boston were unfavorable for registering conspicuous standing-water phenomena, and it is not surprising that the fact of recent deep submergence has not been generally recognized. The inconspicuous evidences exist and are

the same as those found in New York and Vermont under similar conditions.

The rock and drift hills exhibit denuded slopes and softened or smoothed surfaces, silted hollows, and horizontal lines of the water deposits against steep and irregular slopes. Massive kames will usually show evident effects of wave-work.

The territory southwest of Boston plainly shows the effects of standing water as the latest occupant of the region. From sealevel up to 200 feet detrital plains are common. They have been referred to glacial lakes (57, 66, 67, 68, 73). As all the region lies open to the sea, it is only by violent assumptions that effective barriers can be erected. The plains occur at all levels, which is quite unlikely for waters held up by ice barriers, as such waters are too ephemeral and local to produce series of declining levels. This is well illustrated by Clapp's figures for the sandplains in the supposed glacial Lake Charles (68, page 202). His list includes 30 plains, ranging from 60 feet in altitude up to 270 feet, the greater number being 150 and 170 feet, with some at 200 feet. The several difficulties which he admits—the presence of boulders of such large size as to be inconsistent with work of rivers and shallow waters (page 208), the wide distribution of plains with the same level in both the Sudbury and Concord valleys (page 210), and the high plains at 270 feet (page 212)—all disappear with continental uplift out of waters confluent with the sea.

The villages of Wellesley, Natick, Cochituate, South Framingham, and Ashland are on plains higher than the lowest pass to southward flow. This pass lies two miles south of Natick and one-half mile west of Morseville, with altitude 140 feet. This rules out ice barriers on the north, and the direction of glacier flow over the region makes ice barriers on the seaward side quite impossible.

The hills of the district which are high enough to register the summit marine waters are mostly isolated, steep, and in forest; but some weak evidence of the summit wave action should be found. Examination of the Nobscot Hill mass, five miles north by west of South Framingham, will probably find deltas on the streams from higher ground at about 330 feet.

DELTA OF BLACKSTONE RIVER

The two larger rivers with southward flow from unsubmerged ground are the Blackstone and the Quinebaug. The delta of the latter is in Connecticut and will be mentioned later. The delta of the Blackstone is found in good form at Saundersville, combined with the deposits of

the Quinsigismond River. The delta of the latter occupies the valley west of Grafton, extending from Goddard Pond south to the junction with the Blackstone Valley. The Blackstone delta forms extensive plains north of Saundersville, and is graded up stream, westward, past Wilkinsonville. The full height of the delta at Saundersville is at least 330 feet. The railroad station is on a plain at about 315 feet, but a good terrace near by is 15 feet higher. The plains on the north are inferior and are complicated with effects of artificial ponding. Going northward the staticwater features can be seen from the highway toward Grafton, crossing the Quinsigismond River. At the crossing of the river, on the west side, is a good terrace at about 330 feet. Between the two rivers the road lies along the west, or rear, edge of the detrital plain with altitude of 330 to 335 feet, by the map.

SHARON-FOXBORO-WRENTHAM PLAINS (DEDHAM AND FRANKLIN SHEETS)

In the southern part of Norfolk County is a series of sandplains of much importance in this study. They lie precisely on the main divide between north and south drainage, and can not, therefore, by any reasonable theory be attributed to glacial lake waters. Whether interpreted as outwash plains or as erosion plains, they are certain proof of standing water. Their altitude is pratically that of the marine summit level.

The village of Sharon is on a hill of till which has its south end wave-cut at 300 feet, by the map, which is the theoretic figure for the total uplift at this point. Less than a mile southwest, toward Sharon Heights, is the north edge of the most extensive summit-level sandplain found in Massachusetts. The elevation here is about 285 feet. An extensive excavation for gravel has been made by the railroad.

Along the improved highway toward Foxboro the level plain extends unbroken for two and one-half miles, with altitude 285 to 290 feet. The marine level is about 300 feet. The 10 feet depth of water permitted effective leveling of the glacial gravels by wave and tide. Approaching the creek south of Billings Pond, kames and kettles occur at a level inferior to the plain. East of the Neponset Reservoir the ground, at 320 feet, is stony and unaffected by wave-work. Dropping toward 300 feet, the surface is a rolling gravel plain, with some kettles and unleveled kames; but falling to 300 feet, approaching the Catholic cemetery and the four corners, the plain is very smooth and cultivated.

At the northern edge of Foxboro village, corner of Pleasant Street, a stream-filling lies at 300 feet. Above that level the gravel knolls are not eroded. Exposed granite bosses carry glacial scoring, with direction northwest by southeast.

Northwest of Foxboro is a plain contoured up to 300 feet. Above that level is a heavy, unaffected moraine, the limit of wave-work being fairly clear. Going west toward Wrentham the surfaces below 300 feet are water-laid materials, with several gravel pits. The morainal ridge crossed by the electric railway shows wave erosion at 300 feet, with numerous boulders.

West of Wrentham village is an extensive kame area, leveled by waves, which includes Archers Pond and Lake Pearl (Whiting Pond of the map). The amusement ground, called "Lake Clear," is between the two lakes and on a kettled plain at about 250 feet. Northwest of Lake Pearl the surface is kamy and unleveled, but approaching Franklin the surfaces at 260 to 280 feet are smoothed; but a mass at over 300 feet is unaffected moraine.

Southeast of Foxboro, toward Mansfield, the inferior plains are 280 to 200 feet, the village being on a plain at 180 feet.

SOUTHEASTERN LOWLANDS

Southeast of the Blue Hill Range and the summit plains of Sharon-Foxboro the land is below the summit marine level and has recorded in wave-work only that of the shallowing waters. Exceptions are the hills in Plymouth, a few high points in Falmouth, and the highest land of the Cape Cod Peninsula.

The numerous "ponds" in the lowlands doubtless occupy ice-block kettles, which suggest the loaded and anchored condition of the lower portion of the thinning ice-sheet. The intervening land spaces are wave-leveled sands or silts or wave-smoothed drift.

The district of Plymouth is kame-moraine, extensively smoothed by wave-work. The horizontal lines are conspicuous. From any commanding point—the top of the Hotel Pilgrim, for example—the levels show in all landward directions, at 100 to 120 feet elevation. The numerous lakes occupy kettles in the drift which escaped filling. Judging from the topographic maps, the surfaces of the Plymouth, Abington, and Duxbury quadrangles will show abundant evidences of standing water.

The water-laid deposits on Manomet Hill have been described, page 608.

The inferior smoothed and leveled tracts are too abundant and well recognized to require description. A good display of sandplains is seen along the electric railway from Plymouth to Brockton. At Kingston and westward is a wide plain at 100 feet; at Oakland Square, one with kettles at over 100 feet; at Mayflower Grove a tract of leveled kames

with kettles; at Bryantville a rolling plain at 100 feet; and at Bonney Hill a smoothed ridge at 140 feet. It is probable that the sites of most of the villages have been determined by plains with better drainage.

BARNSTABLE AND CAPE COD

Besides the argument supplied by the neighboring territory for lower altitude of the moraine belt, there are intrinsic evidences of submergence:

1. Superficial stratified sands and gravels at high levels or the frequent stretches of horizontal water-laid deposits.

2. Areas leveled by wave-work, shown conspicuously by the horizontal lines in many landscapes. The hill summit at Woods Hole, used for the golf links, is leveled at about 130 feet. Two miles south of Barnstable village is a wide gravel plain at 80 feet (47, page 94). All of the Cape Cod Peninsula shown by the Wellfleet and Provincetown sheets has the hilltops wave-planed. The Highland Light plateau, at North Truro, has been mentioned. On the massive, stony moraines the wave-eroded surfaces are not common in such form as to be unequivocal and are elusive features, which can be seen when sought and may be unrecognized or ignored when not in harmony with the student's theory.

3. The prevailing compact and unassorted structure of the lower gravels. These lack the bedding which is quite inevitable in shallow-water deposits. Subsequent wave-work in the shallowing waters has produced some stratification of the surfaces.

4. The subdued, billowy aspect of the heavier moraine. The hills and knolls usually lack the harshness and asperity commonly seen in land-laid moraines. Of course, this feature is comparative and the personal judgment requires experience in different fields.

An argument against submergence might be found in the existence of considerable irregularity of surface or topographic relief, not only in the stony moraine tracts, but in the sandy Cape Cod belt. It might be asked, how such irregular surface of sand and gravel could persist in the face of the open sea while emerging from the water. The answer involves some factors of the geologic dynamics:

(1) The relief was not nearly as great when the planing occurred, but has been increased by the subsequent slumping due to late melting of buried ice blocks. The presence of many and large kettles is not an argument against submergence, but in its favor, since it appears that the melting of buried ice is very slow until the deposits are exposed to the air (74, page 232). Kettles appear to be much more abundant in moraine and kame areas laid under standing water.

(2) The zone of the wave attack was constantly shifting during the rise out of the sea.

(3) The inhibiting effect of sandy slopes (77, page 301) and of boulder-studded surfaces was considerable. However, we do see evidence of erosion that was not done at the present land level. The valleys in Truro and Wellfleet across the belt of land are apparently the effect of marine erosion.

RHODE ISLAND

The summit level of the Blackstone River has been described. Examination of the valley below Saundersville will find the inferior plains. The city of Providence is built on the lowest plains, mostly less than 100 feet altitude.

The theoretic figures for the Providence quadrangle are 295 feet for the northwest corner and 255 feet for the southwest corner. The city of Woonsocket lies just over the northwest corner and on the Burrillville quadrangle. Southeast and south of the city is a handsome gravel plain with altitude 290 feet. This is reached by the electric railway leading to Providence. The south edge of the plain is a mile south of the city, at the junction of Park Avenue and Smithfield Street, where the railway has an excavation for gravel. The plain is here utilized for a race-track. The plain extends northeast, abutting against wave-washed rock slopes. Northward it becomes irregular in surface, of varied composition and including boulders. It is a typical outwash plain, laid at, practically, the marine summit.

At the southwest corner of the Providence quadrangle lies another excellent sandplain, at near the marine summit. Two miles west of Knightsville the west-leading road climbs by a cut to the so-called "Dugaway" hill and for a mile lies on a level plain. The altitude is 240 feet, representing perhaps 15 feet of submergence. The plain terminates westward against a rocky morainal slope on the edge of the Burrillville sheet, where a cliff, bare ledges, and a boulder field mark the shoreline.

The Neutaconkanut Hill and Park, a mile west of Olneyville, is an example of a wave-washed hill. The bare rock summit is 260 feet, just about the summit water level. The drift has been swept off and rinsed down the slopes. Almost no foreign stones remain on the east and southeast side, where exposed to heavier storm waves, but on the sheltered slopes foreign boulders are piled with the native rocks.

Many inferior plains are noted in the Providence district. The north part of Olneyville has been widely excavated for gravel up to 180 feet.

Westward the ground has been smoothed at 200 to 220 feet. Nearly all the surfaces below 100 feet are sand.

In the district of Fall River the wave-work was erosional on the hills of massive and very stony moraine. The Townsend Hill, three miles southeast of the city, clearly shows wave action up to 230 feet, the theoretic limit. Less evident features occur on the west side of Pocasset Hill.

The evidence of the recent rise of the New England coast is plainly seen from the railroad between Providence and New London, in numerous plains, up to height of 160 feet. The southeast portion of the Kent sheet indicates deltas of south-flowing streams at the summit level, 210 to 215 feet. Good deltas should be found in the valley of Wood River, the southwest portion of the Kent quadrangle, at the theoretic levels.

EASTERN CONNECTICUT

All the drainage of eastern Connecticut is southward, mostly being gathered into the Thames River. Numerous fillings of standing water lie in the region, and are conspicuous by contact with the rough and stony hills.

Three miles northwest of New London is an excellent outwash plain, locally known as the "Mile Plain," which carries the Kenyon greenhouses. It rises from 160 up to 180 feet. Excavations show the fine horizontal bedding. Kettles occur at 165 to 170 feet, and the sharp limit against the stony till is 175 to 180 feet. The marine summit is about 200 feet.

Between New London and Norwich, along the Thames estuary, many elevated, but inferior, plains are seen, from 90 to 160 feet. Examination of the lateral valleys will discover summit plains at higher levels.

Plains in the western part of Norwich are 100 to 120 feet altitude, while the valley of Yantic River, west of the city, holds evidences of standing water from 200 to 220 feet. The Norwich sheet suggests a wide valley filling five miles west of the city, at Bozrah Street, in the valley of Gardner Brook at 200 feet and 220 at the valley head.

The Quinebaug River, with a large drainage area extending into Massachusetts, holds very heavy delta deposits. These begin at Jewett City and are heavy in the open stretches of the river valley and tributary valleys to Putnam. The writer has traced them as far north as Killingly (Dayville). Careful measurements will determine the summit levels as about 240 feet at Jewett City, 250 at Plainfield, 260 at Wauregan, 275

at Killingly, and 285 to 290 at Putnam. At or above Putnam the gravels will be found aggraded above the marine plane.

The Willimantic and Nachaug rivers unite by the city of Willimantic, which stands on the lower plains of the combined delta. The Nachaug delta lies northeast of the city, where the railroad to Boston has a deep cut in the gravel plain, contoured at 260 feet. On the west side of the river the edge of the detrital filling lies along or just below Ash Street for one and one-half miles. The junction of Ash and Jackson streets is on the border of the plain, with altitude about 255 feet. The theoretic marine plane is here 260 feet.

The delta of the Willimantic River lies west of the city toward South Coventry, where plains fill the entire width of the valley at about 270 feet. In the west edge of the city, by the cemetery, the plain is contoured at 260 feet. This district deserves careful study.

MOUNT DESERT, MAINE

In this study of recent change of land level Mount Desert has peculiar interest because of the writings of Professor Shaler, and the eastern part of the island has been examined. No one could reasonably appeal to glacial waters on the steep coast, and standing-water phenomena are positive proof of submergence. Because Professor Shaler carried supposed wave-work to a height of 1,300 feet, it is apparent that discrimination in the study is necessary and the criteria should be considered.

On rock hills, especially of crystallines like those of the island, wave-work of brief submergence can not be conspicuous. The standstill was not long enough at any level to allow benching in the rock, and any fainter inscriptions are likely to be destroyed by the thousands of years of exposure in the severe climate. On the hills the most probable evidence of submergence is the rinsing effect of storm waves—the removal of the glacial drift from the rock surfaces. Even this may be difficult of determination, especially in the forest after frost-work has riven the ledges and snow and ice and tree roots have dislocated and shifted the loosened blocks. A safe criterion is the nature of the material. The weathering produces angular material of the ledge rock, to be discriminated from glaciated and foreign stones. At high altitudes the atmospheric work may denude the steeper slopes of all drift except larger blocks, but the presence of boulders of such shape or position that they could have been tumbled away by storm waves may be taken as proof of lack of submergence. On the other hand, stretches of bare, level rock, or areas with little slope, where some glacial stuff should lie if the area

had been subjected only to atmospheric agents, yet destitute of drift, may be regarded as having been wave-swept; and surely so if they fall beneath the level of the marine plane. For example, the highest points on the road from Seal Harbor to Bar Harbor are the crossings of two rock ridges with altitudes of 240 feet by the map. The granite ledges here are entirely bare. The ice-sheet must have rubbed some drift into the hollows or dropped it in the lee of ledges. Storm water could rinse off the finer stuff and leave some coarser as talus, but these ledges have nothing which heavy waves could joggle off.

With reference to the constructional effects of submergence—the deposits—we may postulate the following, based on the mechanical conditions:

(1) Subglacial till, left only in protected places.

(2) Kames or glacio-aqueous deposits at the higher levels of the sea.

(3) Unassorted gravel and sand at inferior levels, a homogeneity of heterogeneity or pell-mell structure.

(4) Deltas or stratified deposits, of glacial outwash only at the summit marine level and of land drainage at the summit level and all inferior levels.

(5) Silt or clay in sheltered places of deeper water and now at lower levels.

(6) Sands over silts and on other surfaces protected from the rinsing work of waves during the land uplifting.

(7) Possible veneer of gravel in places where wave-work on the rising land was competent to distribute materials, but not to wholly remove them.

(8) Wave-swept bare rocks at all levels beneath the marine summit.

Exposures of number 1, true till, are found in road cuttings. This is the subglacial drift which was left either in deep water or in sheltered places. The englacial and superglacial drift was dumped from the ice-front or carried out by the drainage to produce number 3 in the deeper waters or number 4 in shallow water. The rock flour, or fine suspended material, was swept out, some of it being left as number 5. The most common deposits are the pell-mell gravels, number 3. Exploration was not carried far enough to identify number 2. The more evident and unequivocal proof of the standing water is number 4.

Evidence of submergence was first sought, not on rock slopes and exposed headlands, but in the sheltered valleys, and an excellent outwash plain was found close to Seal Harbor. Passing north up the road toward Jordan Pond, bedded sands are found from sealevel up to 200 feet. A

series of low benches occur, the strongest at 100 feet. At about 140 feet horizontal gravel overlies finely laminated silty sand, and the gravel, with imbedded boulders, continues to 160 feet. After a low cliff the gravels continue as a flat, at 175 feet, to a steep cliff, the front of an outwash plain. At the top of the cliff, on the west side of the road, is the village cemetery, occupying perhaps a couple of acres, perfectly level. On the east side an excavation for gravel exposes a good section of delta structure, with foreset and topset beds. The top of the pit is the height of the cemetery, and the plain, at 200 feet, extends half a mile, to Jordan Pond. The width in the forest is unknown, but it probably fills the valley between the Triad on the east and Jordan Hills on the west.

This plain, with its declining levels and its structure and its position facing the sea, is proof of submergence to 200 feet. It does not represent the initial water surface, and the fine sands suggest considerable depth of water. The plain is not connected with any land drainage and was glacial outwash under perhaps 50 feet of water. The Jordan Pond Hotel stands on a stony plateau, a wave-swept moraine, by the map 20 feet higher than the sandplain. It is the moraine built at the edge of the ice which supplied the outwash for the sandplain.

Along the roads over the hills east of Seal Harbor the gravels and sands occur up to over 225 feet and lie yet higher on the County Road, reaching to 240 feet southwest of Newport Mountain. The water-laid deposits are more abundant in the hollows and localities screened from heavy waves and are increasingly abundant at lower levels.

Between Seal Harbor and Northeast Harbor plenty of standing-water phenomena occur at high levels. Flying Mountain, two miles northwest of the latter harbor, shows a remarkable flat top contoured at 260 feet.

Extensive exploration of Mount Desert will confirm the fact of submergence to about 250 to 260 feet for the south end and perhaps 300 feet at the north end.

Visits have been made to Portland and Rockland districts, and conspicuous effects of the sea are found up to 200 feet. The land has too high relief to accept and preserve strong evidences of wave-work at high altitudes. On suggestion of Professor Woodworth, a visit was made to Blackstone Hill, some eight miles north by west from Portland. An excavation in stratified gravels occurs at about 280 feet and gravel with included boulders at 300 feet. The oval hill, probably a drumlin, is smoothed to the summit, 505 feet. As this is slightly under the theo-

retic marine level, it suggests wave erosion, but the long-time cultivation of the hill makes the matter equivocal. Poplar Hill, three miles north of Blackstone Hill, appears decidedly flat-topped, as if truncated, at 472 feet. The valleys of the district are partly filled with water deposits.

At Rockland, Rockport, and West Rockport the ground up to 300 feet is clearly wave-swept. A mile northwest of West Rockport an excavation on the slope shows an outwash delta at 290 to 300 feet.

Glacial Lake Plains

Below the summit level of the invading sea, indicated by the isobases of the maps, glacial waters were impossible; above that level they could and did occur. A few glacial lakes have been and will be briefly described.

The Warwick sheet, southeast corner, shows a wide valley-filling south of Orange, the village on Millers River, northern Massachusetts. The heavier lake deposits are in the southern part of the valley, south of Eagleville. The outlet was southward by the passes, now under 580 feet.

The glacial waters of the Nashau Valley, described by Crosby (58), have been referred to, page 620.

A local glacial lake was held in the Chepachet Valley, in Rhode Island (Burrillville quadrangle). The valley has a long stretch declining northward, which favored ice blockade. The Acote Hill, close to Chepachet village, and famous as the fort in the near-battle in the Dorr Rebellion, 1842, is a wave-leveled hill of gravel with altitude 500 feet, now carrying the village cemetery. The point of hill on the south shows similar planing. This stage of the Chepachet Lake apparently had its outlet by a channel a little over a mile east of Acote Hill.

The capacious Narragansett Valley held a lingering lobation of the waning glacier which probably blocked the drainage from the west in the Providence district. Sandplains so far above the marine level that they may be attributed to glacial waters have been seen at Greenville, North Scituate, and east of Coventry.

A fine stretch of sandplains lies in the basin of the southwest branch of the Pawtuxet River, between Coventry and Washington (Kent sheet). The plains form the north bank of the Flat River reservoir. They were built of detritus carried in by several south-flowing streams and are outlined by the contour of 260 feet. This is only about 10 feet higher than the marine level indicated on the map, and it is possible that these plains correlate with the sealevel waters.

Another group of high-level sandplains is found at North Scituate, on the Burrillville quadrangle. The higher plains are 300 feet, under the village and a mile north, with filling of the head of the Moswansicut River, near Elmsdale Corners, at 280 to 290 feet. By the isobases the marine level is 265 to 270 feet. The drainage was freely southward and the ice barrier would have to lie south or southwest of Providence.

Smoothed areas are seen at Greenville, about four miles northeast of North Scituate and eight miles northwest of Providence. These areas are also 300 feet elevation, but lower plains lie at 240 feet. The marine level is 270 feet or more.

All these plains are so little over the marine summit as to be somewhat doubtful. There is good opportunity in the area west of Providence for careful, discriminating study.

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